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European Science Notes Information Bulletin  
Reports on Current  
European and Middle Eastern Science

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Computer Science  
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Telephone: 44-71-409 + ext.

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U.S. Mail Address  
PSC 802 Box 39  
FPO AE 09499-0700

U.K. Address  
223/231 Old Marylebone Road  
London NW1 5TH

TELEX: (900) 7402119 ONRE UC  
OMNET: ONR.EUROPE

FAX: 44-71-724-7030; 44-71-723-1837  
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# ESN INFORMATION BULLETIN

This publication is an official publication of the Office of Naval Research European Office. It describes research that is being conducted in Europe and the Middle East.

Commanding Officer ..... CAPT John M. Evans, USN  
 Scientific Director ..... Dr. Arthur M. Diness  
 Editor ..... Ms. Maureen L. Long

**92-04**

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## Computer Science/Computer Engineering in Central Europe

*by Dr. Miroslaw Malek, the Liaison Scientist for Computer Science and Computer Engineering in the Office of Naval Research European Office. He is on leave from the University of Texas at Austin, where he holds the Bettie Margaret Smith Professorship in Engineering in the Department of Electrical and Computer Engineering.*

### INTRODUCTION

This report describes my impressions and provides a preliminary assessment of the status of computer science/computer engineering research and education in Central Europe (Czechoslovakia, Hungary, and Poland). Additional information on this subject is provided in ONREUR Report 92-6-R. It is based on visits I paid to each capital city. Ideas for promoting American-Central European cooperation are outlined, including a plan for organizing a series of three workshops to advance the state-of-the-art in high-performance computing.

### OVERVIEW AND BACKGROUND

During my short visit to Czechoslovakia, Hungary, and Poland in April 1992 I had candid conversations with top computer scientists in all three countries. Their views on the status of science and research there range from catastrophic to cautiously optimistic. I report here on what I learned from them and the impressions that I formed.

#### The Labor Pool

The main concern of technical people seems to be that headhunters from European Community (EC) countries (mainly Germany, France, and the United Kingdom) are luring away the best minds among students and faculty. It requires stamina, eternal optimism, and a total commitment to research to decline offers that exceed current professional salaries by a factor of 2 to 3, since current academic salaries are about \$200 per month! In some cases, especially in Poland, students who work for software houses earn from two to five times more than their professors.

In this situation it is very difficult to attract new researchers to academia and, if this trend continues, universities will be depleted of quality instructors and researchers. The ones who remain are usually either the established, senior academics or the younger optimistic ones hoping that the situation will improve. (To them at least now there is room for hope.) Many of them are involved in some sort of business on the side—some related to computers such as software development and computer services, others in unrelated fields such as import/export or the general service industry.

#### Cooperation with the U.S. and Europe

All of the scientists in all three countries are excited and hopeful about cooperation with U.S. researchers. They are very much in favor of technical interactions, especially joint research and/or exchange programs for students and faculty. They are quite realistic in recognizing that any special programs would be only short-term fixes, so they are very much interested in long-term solutions such as linking themselves to the world science community. They have also expressed strong interest in joint National Science Foundation (NSF) (or any other U.S. agency) programs that stimulate research cooperation. Even modest, low-cost programs would be of interest to them. Their realism extends to expecting neither strong nor fast responses from the U.S.

A relevant support program in the form of grants would be welcome. It was evident that modest programs of this kind would have a stabilizing effect during these turbulent times and would prevent mass exodus from academia until the situation becomes normal. (These countries believe that they have been assured of becoming full members of the EC by the year 2,000. Neither their computer

science research nor their political stability may last without earlier outside attention.)

The Central European researchers would also appreciate having access to U.S. databases and current information on grants, scholarships, fellowships, and other programs. Usually, research initiatives announcements for which they are eligible are not distributed to them or are so delayed that application deadlines are often missed. They are also hampered by inappropriate administrative and support structures in all three countries.

It is important that U.S. research and development (R&D) agencies explicitly describe to the foreign technical communities they visit

- what characterizes their agencies and activities in the U.S.,
- how they fit into the U.S. national R&D scene, and
- what their outputs are.

This is especially true for military R&D organizations (even U.S. ones) because of the residual stigma attached to the military from the past.

It is also important that organizations such as the Office of Naval Research (ONR) clearly define to themselves and to the Central European research communities their goals, their role in Central Europe, and the types of programs they can or cannot consider implementing with computer science researchers in Czechoslovakia, Hungary, and Poland.

Links already exist with the EC via two programs, TEMPUS and ESPRIT. TEMPUS focuses on education and student/faculty exchange; ESPRIT promotes joint research grants (for example, Polish scientists will participate in 13 ESPRIT programs).

Grants are usually about 20,000 ECU (\$26K), and the upper limit is 100,000 ECU (\$130K). Also, a few scientists from all these countries have direct links, mainly with American, French, and German researchers, and some of them have already spent some time in the United States, usually teaching courses or doing research at U.S. universities.

### Academic Programs

The level of academic programs in all three countries is good. Many state-of-the-art courses are available including software engineering, robotics, neural networks, parallel algorithms, and computer architecture (including multicompacting). The students' laboratories mainly have IBM clones, but several laboratories are already equipped with SUN workstations (including Sparcs). IBM RISC/6000s,

VAXes, IBM mainframes, and even Evans and Sutherland graphics stations as well as parallel systems based on transputers (Supernodes) and Convex are also available.

The U.S. embargo was recently lifted, and it seems that especially workstations will begin to flow in. SUN and others are offering university discounts (at least at present in Poland, where there are three SUN dealers).

### Research Perspective

The level of research varies. In some areas it matches the highest standards; in other areas it seems to be lagging immensely. Some specifics follow.

### CZECHOSLOVAKIA

Twenty-five top Czech and Slovak computer scientists attended the meeting from 10 institutions. The meeting was held in Prague at the Czech Technical University (CTU), whose Faculty of Electrical Engineering has about 4,000 students and about 900 faculty and staff. Dean Jan Hlavicka was the host and organizer of the meeting.

The main technical concern of Czech and Slovak scientists is their quickly dying, local computer industry, which is no longer able to compete. Traditionally, this industry was supplying local and Eastern Bloc markets, but this customer base has turned to western products.

The Computer Science Laboratory at the CTU is equipped with SUNs (including Sparc Stations) and three VAXes. The scientists would love to have more equipment, but it is not their major concern. The main concern is what to do about graduates who, out of necessity, may soon be looking for work abroad if the trend toward shutting down the computer industry in this country continues. However, there is hope that some companies will invest in Czechoslovakia. Given the status of the world's computer industry, chances seem rather small to me.

Nevertheless, scientists are hopeful, optimistic, and eager to work. They agree that personal contacts with American scientists would help them build strong educational and research programs. In their opinion, the key item needed to improve the situation is to have good and timely information about projects and grant announcements.

Many of the scientists are widely travelled and speak good English. They would definitely be interested in exchanges of students and faculty. Some of them have already spent one or two years in the

United States. They would like, if possible, to have electronic access to selected research databases. This should be considered for implementation.

The Czech Technical University of Prague is opening an English track of education that will have visiting scientists from all over the world as lecturers. The first visitors will mainly be scientists on sabbatical; others will be sponsored by foreign companies and institutions (e.g., a scientist of Czech descent from IBM).

Czechoslovakia is participating in seven EC-sponsored TEMPUS projects. The Czechoslovak scientists would like to extend their cooperation with agencies like NSF, even if the agreement would offer support for American participants only! Contacts and interactions are what are most desired now.

I spoke with Dr. Michael Chytil, the Secretary of the Council for Informatization. He told me that if he gets a positive signal from NSF he would try to arrange some special funds for this program to support Czech and Slovak scientists in cooperative efforts with the U.S. The grant program is in place, and they would like to enter joint proposals with NSF or other U.S. agencies and institutions. Because the number of computer scientists here is small, it is very difficult to get an unbiased evaluation of proposals; they would welcome an outside, objective judgment to improve the quality of their review process.

Specific research projects are described in ONREUR Report 92-6-R. These descriptions are intended to relay the research efforts, accomplishments, and interests of Czechoslovak computer scientists. By no means should they be considered to be research proposals. However, anyone with similar research interests is welcome to contact them.

The major research areas in Czechoslovakia include fault-tolerant computing, testing, application-specific simulation, software verification, optimization, neural networks, distributed systems, stochastic informatics, formal methods, decision support systems, and concurrency. Several areas, especially fault-tolerant computing and simulation, appear to me to have some state-of-the-art projects.

Key institutions for computer research (based on one day impressions) are:

- Institute of Information Theory and Automation and Institute of Computer and Information Science at Czecho-Slovak Academy of Sciences, Prague
- Czech Technical University, Prague
- Charles University, Prague

- Slovak Technical University, Bratislava
- University of West Bohemia, Pilsen.

Czecho-Slovak scientists have written numerous books and have published extensively in local and foreign journals. They have close contacts with a number of West European and some American institutions (including the University of Texas at Arlington, the University of Hawaii at Manoa, and the University of Denver) but are very much interested in developing cooperation with other American universities, industry, and government institutions.

## HUNGARY

Twenty-five top Hungarian computer scientists attended the meeting at the Technical University of Budapest. The Department of Measurement and Instrumentation Engineering of this university is the only electrical engineering department in Hungary; another one in Szeged will soon be in operation. The department in Budapest will probably change its name to reflect its research in computer engineering; with its world-class expertise in some electrical properties measurements, the name should also reflect its instrumentation section.

As in Czechoslovakia, the concern here is the extinction of the hardware industry. But, on an optimistic note, the software industry is growing; there is a feeling that software research has a tremendous future in this country. The problem is that faculty background is mainly in hardware. It would be a loss, and probably an impossibility, to quickly shift the educational programs to software.

The range of courses offered in computer engineering is quite impressive. It ranges from foundations for computer science to software engineering, computer-aided design, machine intelligence, robotics, and computer systems. Content descriptions meet American standards. The glossy prospectus of the Technical University of Budapest could compete with the best from the United States in its form and content. It is an informative publication.

Research depth is mainly in dependable systems (diagnosis, high reliability with small redundancy), instrumentation (intelligent measurement systems, measurement and processing of visual information), computer-aided logic synthesis, intelligent robotic systems, computer graphics, computer engineering in control systems, formal methods, software engineering, complexity, databases, parallel processing software, and simulation.

Scientists have links mainly with Western Europe, although there are also some contacts with

the U.S., Czechoslovakia, and Estonia. Some researchers have spent a year or two in the United States.

Key institutions in computer research include: Technical University of Budapest; Institute of Informatics, Budapest; Research Institute for Measurement and Computing Techniques, Budapest; Hungarian Academy of Sciences, Budapest.

In addition, a special program called the Information Infrastructure Program (IIF) for Research, Development, and Higher Education (1991-1994) is supported by the National Committee for Technological Development, the Hungarian Academy of Sciences, and the Hungarian National Science Foundation to develop a national computer network.

Hungarian researchers are well organized; already more than 90% of their projects are externally funded. As mentioned earlier, they have quite a lot of cooperation in effect with Western Europe, but links with the U.S., especially in the area of joint workshops, are missing. Problems with faculty leaving academia are not as severe here as in Poland. Hungarian strengths, especially in instrumentation, should be of interest and value to U.S. research programs, and the existing cooperation should be expanded.

## POLAND

The seminar in Poland was attended by about 25 scientists. It attracted the *creme de la creme* of Polish computer academics from all the major research institutions in Warsaw, Gdansk, Cracow, and Wroclaw. The only group missing was from Poznan: Prof. Cellary and his colleagues were busy setting up the Ecole Franco-Polonoise de Poznan (French-Polish University for Computer/Communication Technologies), which will open in the fall, 1992. It will be the first French "Grande Ecole" in Poland (!), and its supporters are the cities of Poznan and Rennes, Polish Ministry of Education, France-Poland Foundation, governments of Brittany and Ile-et-Vilaine, and major French high-tech companies such as France Telecom, Bull SA, and Alcatel.

The main problem at Polish universities is the loss of the existing faculty and the inability to recruit new faculty because of highly competitive offers from local industry and abroad. Not surprisingly, the discussion concentrated on how to preserve the existing human resources and to reverse this situation.

The benefits of actions such as those described above may be enormous. Proper direction and focus can unleash the intellectual powers of many researchers who can make lasting contributions to

computer science. This process may in effect strengthen the U.S. positions in striking cooperative program deals despite German and French activities to date, and may also strengthen political stability in those countries. It may also contribute to amplification of program effectiveness in the U.S. and abroad.

Most of the professors are well traveled and have rather close ties with American and West European scientists. The relatively large Polish-American community in the United States, coupled with significant research contributions, especially in mathematics, provide a number of opportunities to establish close contacts with American science. Poland has many traditional ties with the U.S. Also, Warsaw is one place where East meets West with ease.

Unfortunately, the \$10M Marie Curie-Sklodowska Fund, recently established and managed by the American Embassy in Warsaw, is dominated by physicists; thus, Polish computer scientists have practically no access to it. I talked with an official at the embassy and was told that in the second round of grant distribution they were planning to add electronics but not computer science!

The accomplishments of Polish computer scientists are well known, especially in areas of concurrency, algorithm theory, parallel algorithms, computer graphics, languages, software semantics, numerical analysis, algebraic theory, specification language, rough sets theory, parallel processing, distributed systems, complexity, operating systems, graph theory, formal methods, system reliability, safety, and security.

Some of the academics are at Berkeley, Carnegie-Mellon, and Columbia as visitors. They still seem to shuttle between Poland and the U.S., but the question is for how long. Professor Turski of the University of Warsaw responded to my question on why America should try to save Polish science. He noted that over the last 50 years Poland has provided America with many brilliant scientists.

If nothing is done, this pipeline of intellectual energy will be broken, so it is in the interest of America to keep it open. This seems to be true from all aspects, but I wish that a rationale more positive for Poland would have been presented as well. I also strongly believe that opening an American University in Warsaw would give a different dimension to Polish-American relations, not to mention its stabilizing effect on science—ultimately saving it from destruction.

Another short-term solution voiced by the Poles would be a special grants program. Polish scientists would like to have a mechanism with direct impact on research support. It would boost research activity

and allow them to persevere in this difficult time until the situation becomes stable. Their basic income is of fundamental concern to them.

Poles will participate in 13 ESPRIT projects (totaling about 100K ECU (\$130K) funding) and will also participate in EC's TEMPUS program. They have some direct ties with NSF programs, but these are small and mainly focus on travel and short visit support—not on research grants.

The newly established Polish Society for Information Technology produces a monthly bulletin in which it outlines the strategy for revitalizing computer science in Poland by close ties with the computer industry, especially in the area of software services. The lengthy document describes in detail the proposals for development of information technology in Poland.

There is definitely an interest on the part of this society in incorporating Poland into the EC and U.S. research communities, so joint grants with NSF and others are of interest. Exchange of faculty is a form already practiced. Exchange of students and faculty frequently ends up to be "a brain drain;" many of them simply do not return. Until the situation in Poland changes for the better, this process will continue.

Laboratories here are generally equipped with IBM clones, SUN workstations, and some parallel computers, IBM mainframes, and VAXes. Among several interesting projects, I was most surprised to see a Pascal translator developed for the Array String Processor. This project from Brunel University (London) is supported by the U.S. Navy and the U.S. Air Force Rome Laboratory, and is, I believe, already installed in some systems. Dr. Chrzastowski of the University of Warsaw told me that there would be no problem in extending the translator to support Ada and Fortran. This translator converts the high-level language program in the ASP language, which, in turn, is compiled to produce machine-executable code.

## WORKSHOPS

There is great interest on the part of computer science leaders in organizing top-quality workshops in all three of their countries. I was quite pleasantly surprised when Polish scientists suggested the organization of a workshop on Models for High-Performance Computing, with special emphasis on concurrency. This topic coincided with my presentation in Washington D.C. during the ONR Computer Science Program review on January 30, 1992, in which I noted that models seem to be a major bottleneck in

development of high-performance computer systems! (Such systems are the core of the recent Presidential Initiative on High-Performance Computing and Communications.)

The gain to U.S. computer science would be large if such a workshop were to be implemented. The workshop will be organized by Prof. A. Mazurkiewicz and myself with possible participation of Profs. Chandy (Cal Tech), Valient (Harvard University), Snyder (University of Washington), Hoare (Oxford University) and others. Many of them are ONR contractors. Tentatively we discussed that the workshop could be held in the third week of November (Nov. 16-18, 1992) in Warsaw. This might be coupled with other related events.

Another workshop, suggested by Hungarian colleagues, also fell into computer design methodology and would form an excellent sequel to the one in Poland. It would be on Algorithms and Architectures for High-Performance Computing. The date should be coordinated with related events that will take place in Europe. The timing for this workshop should be Spring or Fall 1993, and the site would be Budapest.

I also think that it would be worthwhile to organize a Workshop on Instrumentation for Computer Systems; this topic is also quite advanced in Hungary. Both U.S. and Hungarian scientists would benefit from the exchange.

To complete the series, I suggested Applications Semantics for High-Performance Computing as a topic for the third workshop. This topic is futuristic and at the moment has very few experts. I think it could be a booster for people who are interested in pursuing this area in Czechoslovakia. It is a crucial area that we also have to stimulate in the U.S. to succeed in supercomputing. This workshop would take place in Prague in the fall of either 1993 or 1994. It could be a strong positive influence on U.S. thought on this topic.

There was also a big interest in organizing a Fourth International Workshop on Responsive Computer Systems, to take place in October 1994. There is a high level of expertise in fault-tolerant computing in Czechoslovakia, a topic inherent to responsive systems and to ONR/US programs.

The appendix outlines plans for potential workshops.

Dr. J. Gorski from the Technical University of Gdansk in Poland also requested additional support for SAFECOMP '93, an international conference on computer safety, reliability, and security, which is scheduled take place in Gdansk, Poland, on October 27-29, 1993.

I am convinced that the suggested workshops would not only accelerate research and development of high-performance computing but would also have an impact on the ONR presence in Europe and on the development of new, exciting relations between U.S. and Central European computer scientists.

I recommend that the subjects and dates of the potential workshops be seriously considered and planned for.

## CONCLUSIONS

The situation in Central Europe, viz., Czechoslovakia, Hungary, and Poland, ranges from catastrophic to mildly optimistic. There is no doubt that years of effort and accomplishments must be preserved and reinforced. There is also no doubt that scientists in Czechoslovakia, Hungary, and Poland, with proper focus, stimulation, and funding, will significantly contribute to the world's computer science.

World-class research is already underway in the region in areas of formal methods, algorithms, software semantics, concurrency, reliability, fault-tolerant computing, simulation and instrumentation. Needs are mainly related to the interchange of ideas and closer ties with international science. They would be welcome. The computer industry is in trouble; perhaps a gradual switch to software research will alleviate the effects of this collapse. Each country has some specific ideas on how to proceed. One common theme is obvious: cooperation and encouragement from the U.S. would be of great help and welcomed, even without substantial financial assistance.

I personally believe that starting some cooperative and/or interactive research programs would not only help researchers to persevere during these

turbulent times of political and economic change, but they would also be of significant benefit to the U.S. and to computer science.

Let me describe one such idea. Based on the French involvement in Poznan and the outlook for human resources (both referred to above), I discussed with Polish colleagues the possibility of opening an "American University in Warsaw" that would serve all of Central Europe and the Former Soviet Union (and would probably attract a number of American and West European students because the education at such a university would be in English). This type of university would allow faculty to have competitive salaries, attract the best talent, and prevent the destruction of the existing structure. This idea will take strong efforts, coordination, and perhaps fervor. Of course, this is a large and special sort of effort, perhaps best considered at the highest levels of U.S. R&D planners.

Various alternatives are available that I think could have a tremendous impact on the American presence in this part of the world. There is a fundamental difference now in these countries. In the past there was not even hope; now with the new freedom comes hope (of becoming an EC member, of better times for personal growth, and of better times for science). This hope should be nourished and supported in small ways by promoting the exchange of faculty and students and by sponsoring workshops and small grants. It can also be done in bigger ways, such as research initiatives and perhaps even by more ambitious efforts.

The potential is there. I propose that individual investigators, professional societies, government agencies, and planners rise to the challenge of the times by considering these suggestions.

## APPENDIX

### Proposed Workshops

Title	Location	Date
Models for High-Performance Computing (HPC)	Warsaw	Fall 1992 or Spring 1993
Algorithms and Architectures for High-Performance Computing	Budapest	Spring or Fall 1993
Applications Semantics for High-Performance Computing	Prague	Fall 1993 or 1994
Additional Workshops:		
Instrumentation for Computer Systems (could also be called Instrumentation for High-Performance Computer Systems)	Budapest	1993-4
Responsive Computer Systems	Prague	October 1994

The cost of each workshop would be about \$5-15K.

# Understanding and Aiding Military Decision Making

by Stanley C. Collyer, Technology Area Manager for Training and Personnel Systems, Office of Naval Technology, Arlington, VA

## INTRODUCTION

The first International Applied Military Psychology Symposium (IAMPS) was held in 1963. Since then it has evolved into an important forum for information exchange among European and North American military psychologists. Attendees are primarily uniformed and civilian psychologists employed by their respective defense establishments. A wide array of topics are typically covered. These include personnel selection and classification, manpower planning, leadership, stress, training, simulation, and human factors. Over the years IAMPS has been hosted by many countries. It has grown in size, although attendance is restricted to provide an atmosphere that encourages discussion. The Office of Naval Research European Office (ONREUR) continues its role as sponsor and coordinator of IAMPS.

The 27th IAMPS was hosted by Sweden's National Defense Research Establishment and was held in Stockholm, Sweden, on June 10-14, 1991. The meeting was attended by more than 50 people from 14 nations.

The National Defense Research Establishment (commonly abbreviated as FOA, from the Swedish *Försvarets Forskningsanstalt*), is Sweden's principal military and civil defense research organization. In addition to psychology, FOA conducts research and development in the areas of physics, chemistry, medicine, and information technology. Behavioral and social science research is conducted in the Department of Human Studies, in such areas as cognition, human factors, human-computer interaction and training.

The keynote speech was delivered by Brigadier General Tode from the Defense Staff of the Swedish Armed Forces. General Tode noted that despite the monumental political changes taking place, aggression is still a fact of life in much of the world, and the need for strong defense forces continues. He stressed the importance of the discipline of military psychology, and pointed out that even with the sophistication of modern weapons, these weapons are still controlled by people who have the same limitations they have always had. Only by understanding human behavior can we hope to maximize the effective-

ness of both the personnel and the equipment that comprise a strong defense force. In particular he stressed the significance of research in human factors and in training, noting that recent experiences in the Gulf War demonstrated the importance of training as a means of helping to counteract numerical superiority.

Three invited papers were delivered; they are published in their entirety as ONREUR Report 92-4-W, "Understanding and Aiding Military Decisions." Two of the papers summarize recent trends in decision-making research, both in Europe (the paper by Prof. Berndt Brehmer) and in the United States (by Dr. Martin Tolcott). The third paper (by Dr. Janis Cannon-Bowers et al.), describes an important ongoing program to improve tactical decision-making under stressful conditions. This is a topic of widespread interest in Europe as well as in North America; the paper discusses the scientific underpinnings on which the program is based.

## DECISION MAKING

A new feature of IAMPS this year was the identification of a special-focus topic to provide the opportunity for more detailed treatment of a subject of current interest. The topic selected for emphasis was *decision-making*, focusing on the development of decision support systems and training techniques for individual and group decision-making in military environments.

Dr. Lars Rejnuš, a Senior Research Officer at FOA, discussed a decision support system called KOBRA, which was developed for responding to nuclear/biological/chemical (NBC) attacks. This system, currently in use, serves not only as a decision support tool but also for training and for generating baseline data in various hypothetical scenarios.

Rejnuš' paper focused on issues related to development of the user interface for the system. A natural language interface was developed that allows even novice users to communicate effectively with the system without extensive training. The system is queried by means of grammatically correct sentences that are constructed in part from sentence fragments chosen from pop-up menus. During system development, substantial attention was paid to usability

considerations, which were discussed. Interface features include a help system, extensive use of windows, ready availability of backup information, key-stroke accelerators, legend text used in conjunction with windows, and the use of colors in geographical displays.

The next generation of this system will have a more advanced capability for generating and manipulating text. Future research will compare the current interface with other approaches now possible with graphical user interfaces (such as MSWindows).

Dr. David J. Hickson, Professor of International Management and Organization at the University of Bradford Management Center, England, presented a paper (coauthored by Sue Miller and David C. Wilsson) on making top-level strategic decisions in public and private sector organizations. The paper was based in part on recently published material by the authors and others.<sup>1,2</sup>

Hickson's work has focused on understanding the various decision-making processes that exist in organizations; he describes three general patterns:

- sporadic processes, in which decision making is drawn out over a protracted period of time, with frequent delays, obstacles, and detours;
- fluid processes, which proceed more smoothly, quickly and systematically; and
- constricted processes, which are more tightly controlled by a fewer number of participants, with less negotiating and consensus-building.

Although not done in a military context, the research can be applied to certain types of military decisions. For example, in examining organizations with structures similar to those typically found in military settings (clear-cut, hierarchical control combined with decentralized, tactical flexibility) Hickson notes that such organizations tend to have unduly constricted decision-making processes.

Future work will concentrate on determining what makes a decision successful—in particular, the extent to which the decision-making process itself affects the quality of the outcome, and therefore what organizations can do to improve that process. Some preliminary speculation on this issue has led to the suggestion that success depends on two kinds of factors: "launchers," which help get a decision moving in the right direction (factors such as timing, relevant experience, planning, commitment by all major participants) and "propellants," which sustain its momentum (expertise, competence, effective lines of control and responsibility).

## PERSONNEL SELECTION AND CLASSIFICATION

The development and usage of tests for determining fitness for military service and for assigning people to jobs for which they are well suited continues to be a subject of interest in many countries. This section summarizes several presentations related to this topic.

Chief Psychologist Johan Lothigius, of the Swedish National Service Administration, gave an overview of activities of the psychologists in his organization. This organization is the enrollment board of the Swedish Armed Forces and is the central authority for enlistment and other personnel matters. The head office is in Karlstad, with five regional offices around the country.

Since the 13th century, Sweden has had compulsory military service for its male citizens. Currently this affects men beginning at age 18 who, after completing basic training, receive periodic refresher training and are subject to callup until age 47. The armed forces have about 40,000 permanent employees, including 16,000 career officers.

Between 50,000 and 60,000 people are enlisted annually. The psychological examinations associated with the enlistment process include the following components:

- a test of general intelligence, consisting of four subtests for logical, verbal, spatial, and technical abilities;
- various biographical and attitudinal questionnaires;
- tests of mechanical abilities and telegraphy tests (not given to all conscripts); and
- an interview and assessment, which is the most important aspect of the psychological evaluation process.

The three principal factors assessed during the interview are mental fitness (about 7 percent are rejected on this factor); ability to cope with the stress of war; and leadership ability. The psychological tests are used, along with preference statements, by an enrollment officer who makes assignment decisions.

Post-enrollment tasks performed by Swedish military psychologists include a continuing assessment of mental fitness, and special missions in education, research, and personnel selection.

Lothigius stated that there is substantial interest in the eventual use of computer-based tests, including a computerized adaptive testing system for

selection and assignment. Potential tests are currently being evaluated and developed.

Dr. Friedrich Steege, of the Psychology Service of the German Ministry of Defense, discussed simulation-based approaches to personnel selection and classification. A premise of these approaches is that the increased realism provided by using computers to simulate portions of the criterion task will yield improved predictive power.

Steege first discussed some constructs provided by cognitive psychology that describe underlying abilities or dimensions that many computer-based tests attempt to assess. For example, the taxonomy described in Ref. 3 lists the following constructs: spatial orientation and visualization, numerical facility, time sharing and selective attention, reaction time and choice reaction, psychomotor skills, and complex information processing. Steege noted that much work remains in developing tests and constructs that open new dimensions in both the predictor and criterion domains, and in using computers to measure abilities that cannot be assessed by paper-and-pencil tests.<sup>4</sup>

After mentioning several recent or ongoing programs to extend the use of computers for testing, Steege summarized recent developments in simulation-based assessment, which has been used effectively in aircraft pilot selection. He noted that the simulation approach allows the most salient features of the task to be emphasized by eliminating other, less relevant, aspects. He then summarized the approaches to pilot selection being taken by several nations and discussed in greater detail the system being developed in Germany. The system, "Instrument Coordination Analyzer" (ICA 90), is a computer-based battery that simulates various tasks relevant to flying. ICA 90 contains five tests that together represent a wide range of abilities considered essential to flying: psychomotor coordination; coding of information and flexibility of mental representation; anticipation of self-motion in space; capacity and strategies of information processing; and problem-solving competence. The test battery is being given to new officers having no relevant flight experience. Baseline data are being collected.

There is a great deal of current interest in Europe and North America in the use of computer-based tests to tap human abilities that cannot be adequately evaluated with traditional tests. Pilot selection is clearly one of the principal areas that is benefitting from this interest, and one in which there is substantial activity in many countries. The need to conduct comparative evaluations of various approaches being pursued is becoming increasingly

clear. IAMPS is one useful forum for information exchange on this topic.

Major Maxon Mosher, Canadian Forces Directorate of Recruiting and Selection, discussed another approach to personnel selection—the use of interviews. Although reviews of prior research have cast doubt on the reliability and validity of employment interviews,<sup>5,6</sup> recent research, involving highly structured interviews, has shown considerable promise.<sup>7</sup> Mosher described a recent effort to examine the usefulness of structured interviews for selecting personnel for the Canadian Forces (CF).

One of the factors motivating this research was recent Canadian human rights legislation, which requires all Federal employers to demonstrate the job-relevance of any information obtained during the selection process. Because job interviews are relatively straightforward to defend on this basis, they may be given greater weight in the future, especially if their predictive validity can be improved.

In general, structured interviews are based on critical incident analyses in which experts identify critical behaviors in various job-relevant situations, and interview questions are then developed that relate to those behaviors. For example, target behaviors of interest in selecting military recruits include:

- conduct (following rules, accepting criticism);
- teamwork (getting along with peers, participating in group activities); and
- coping (adapting to new or unusual situations, reacting appropriately to stress).

Dr. Svend E. Olsen, from the Danish Defense Center for Leadership, presented results from a preliminary study to determine the characteristics of effective tank commanders with regard to "social competence," which encompasses a variety of skills and abilities related to social interaction. The factors judged especially relevant to tank commanders were: informal leadership, flexibility/adaptability, stress resistance, social situational awareness, empathy, self-confidence, and authority.

Results of this work suggested that the most effective tank commanders exhibit a "person-oriented" leadership style. Evidence also supported the hypothesis that more effective commanders possess a greater amount of self-knowledge: the self-ratings made by the more competent commanders tended to correlate higher with external ratings than the self-ratings of the less effective commanders. Self-knowledge has long been considered an important component of good leadership.<sup>8</sup> More generally, issues of small-group leadership, with application to both

selection and training, are increasingly being seen as important areas of research in the context of a variety of military teams.

Lt. Col. Sandro Tomassini, head of the Applied Psychology division for the Italian Armed Forces, presented a paper (coauthored by Lt. Col. Maurizio Laurenti) discussing the procedures for accepting applicants to the Army's Military Academy. He noted that until recently, personality and aptitude test scores were not used to reject applicants but only to group them into five general categories. Their scores on other tests (general culture and mathematics) also affected their final rankings. This procedure has proven unsatisfactory because of high resignation rates and failure rates on written examinations.

A new procedure, now in effect, permits aptitude and personality scores to be used as a basis for rejection, and as a basis for irrevocable assignment to one of three career paths: various Armies, Carabinieri Army, and Logistics Corps. It is believed that this will result in a more efficient and less costly officer selection procedure.

Capt. Antonio Peri, a psychiatrist in the Personnel Branch of the Italian Navy, presented findings (coauthored by Maria C. Ruffini and Andrea Citone) from a study to determine the personality factors and coping skills that are most conducive to working and living harmoniously aboard small ships for long periods of deployment. Overall, the study found morale on the ships investigated to be high, perceived discomfort level surprisingly low, and in general a quite satisfactory level of all socio-emotional factors measured.

Peri pointed out that the results may not be generalizable because of methodological problems and sample size. However, his finding of a positive correspondence between certain socio-emotional factors (morale, cohesion, interpersonal compatibility, general feelings of well-being) and performance improvement over time suggests that selection tests based on such factors may be useful in improving overall operational efficiency aboard ship.

Col. Aurélio Pamplona and Capt. Antonio Roy Costa, psychologists in the Portuguese Army, evaluated the ability of several tests to assess an individual's capabilities for coping with stress. The purpose of the research was to improve the selection process for personnel to be assigned to Special Forces and Commando units. Three types of paper-and-pencil tests were administered: Rosenbaum's Self-Control Schedule, Levenson's Control Locus Scale, and Zung's Anxiety Self-Evaluation Scale. Results showed support for the use of these tests to predict

the ability of students in commando school to deal appropriately with unexpected stressful events. In particular, measures of self-control as indicators of resourcefulness<sup>9</sup> were useful, suggesting that highly resourceful individuals use more effective coping methods when faced with stressful events.

Two psychologists from the Psychology Service of the Spanish Army discussed ongoing activities in their organization. Col. Felix Utrilla Layna described the process by which approximately 200,000 inductees are tested each year, and individuals with suspected psychopathologies are identified. He noted an increasing appreciation for the important role played by military psychology in the Spanish Army. Lt. Col. Pablo Lazaro Pueyo described the battery of psychological tests administered to enlistees. He emphasized those used to detect problems that would render an individual unsuitable for military service. The principal screening tool for identifying possible psychological disorders is a personality test having scales for depression, psychopathic deviation, neurosis, and extroversion. Follow-up clinical interviews are conducted for examinees scoring beyond a critical level on one or more of the scales. Disqualifying individuals for service based on this procedure has resulted in a decline in the suicide rate during the past five years.

## TRAINING

Development of improved instructional methods and cost-effective simulation systems for military training is an increasingly important activity of military psychologists in many nations. Presentations on this subject are summarized in this section.

Dr. Maud Angelborg-Thanderz from the Division of Aviation Medicine at FOA reported on research aimed at determining whether, or to what extent, pilot proficiency can be maintained or rapidly reacquired when flight training is done on an intermittent basis, interspersed with relatively long periods of no training. The research was motivated by:

- questions about how to train pilots who would be required to fly a variety of types of missions,
- concern about rising training costs and decreasing budgets, and
- an interest in being able to periodically use former military pilots now flying for the airline industry.

Pilots who had not flown a particular military aircraft for periods ranging from one-half year to 12

years were given an intensive simulator-based training program. This was followed by evaluations of performance and workload, both in the simulator and in actual flight. Workload measures were similar to those discussed by Svensson in his IAMPS presentation [see below] and reported elsewhere.<sup>10</sup> Performance in the aircraft was generally very good for these pilots. In some cases they performed better than the younger pilots with current aircraft experience, but at a cost of substantially higher workload.

The major conclusion from this work is that highly skilled pilots can recover from long periods away from the aircraft, provided they receive individualized refresher training from experienced instructors who provide consistent and frequent feedback. The work also validated the importance of flight simulators as cost-effective substitutes for actual in-flight training.

Dr. Erland Svensson of FOA's Division of Aviation Medicine presented a paper (coauthored by Maud Angelborg-Thanderz and Lennart Sjöberg) describing research at FOA to develop an index of a pilot's mental workload during a variety of missions. Such an index would be useful, among other things, as a means of evaluating decision support systems, of analyzing specific missions, and of measuring the effectiveness of training. Although substantial progress has been made in the area of workload measurement (see, for example, Refs. 11 and 12), much work remains to be done. Clearly, workload is a multidimensional concept that cannot be reliably assessed by a single measure.<sup>13</sup>

The three general approaches to workload assessment—subjective ratings, objective performance measures, and physiological measures—each have their own strengths and weaknesses. The work described by Svensson attempts to improve the reliability and validity of subjective ratings by combining them with physiological measures into a single index.

Based on results from flight tests, a model was developed that incorporates a set of psychological variables (subjective ratings of difficulty, risk, effort, mood, etc.) and psychophysiological variables (adrenaline and noradrenaline excretion levels). These variables were combined into a Workload Index (WI), which characterizes high workload as consisting of increased tension or mental stress, increased effort (psychological and physiological), and increased energy mobilization followed by fatigue. The WI was validated in simulated and actual flight tests. Results showed it to be a sensitive indicator of experience level, with workload dropping substantially as training progressed.

Svensson reported that work is now underway to compare the WI with other indices, such as the NASA Task Load Index and other indices.

Lt. Col. Jean-Pierre Pauchard, a psychiatrist in the Swiss Army, presented the results of preliminary research into the use of a novel method for leadership training that focuses on the causes of poor interpersonal relationships. This technique, called the Balint group method (named after a 20th-century Hungarian psychoanalyst) was first tested in a military setting by the Swiss in 1985. It is now being used for officer training in the Military Leadership Training School in Zurich. The goal of the training is to teach leaders how to detect, understand, and repair disturbed relationships (with subordinates, superiors, or colleagues) that can undermine the leader's effectiveness, regardless of whether they involve him directly or only indirectly.

The essence of the Balint method is the presentation of a case history in a group setting. As adapted for military leadership training, the group consists of a professionally trained leader and co-leader along with 10 to 12 trainees who listen to one of their group discuss a problem relationship with which he or she is personally familiar. Members of the group ask questions and then participate in a brainstorming session in which observations and personal reactions to the story are discussed; explanations or advice are prohibited. This is followed by a period of general discussion. The aim of the session is not to try to solve the problem, but rather to examine the conditions that led to it.

First Lt. Jürg Stadelmann, a psychologist in the Swiss Army, described a recent project aimed at counteracting a commonly observed phenomenon in many countries, namely a decline in motivational level of conscripts during basic training. He suggested that this problem has increased in the last few decades as the result of a growing disparity between life in the army and the conscripts' civilian family life (which is freer and less hierarchical than in former generations). The approach taken by this research to enhance motivation was to improve the leadership skills of the noncommissioned officers (corporals) who interact most directly with the conscripts.

Leadership training consisted primarily of efforts to improve communication skills to enable the corporals to cope with difficult situations more effectively without resorting to formal authority. Two psychologists supervised the corporals in one company during an eight-week period of basic training, providing suggestions and guidance in daily meetings. The most important training tool was the use of videotapes, which enabled them to provide direct and

concrete feedback. Results showed that conscripts in the experimental group developed a more positive attitude about their training and about the army in general.

## OTHER TOPICS

This section contains brief descriptions of presentations given on additional subjects, including stress, suicide, and factors affecting retention.

Dr. Herbert Aschenbrenner, a psychologist in Germany's Armed Forces Personnel Office, reported on the planned activities of a newly formed NATO Research Study Group (RSG-22, "Psychological Support for Military Personnel"), which he chairs. This study group evolved from a related group whose charter was to develop measurement methods and selection criteria for stress-resistance.<sup>14</sup> RSG-22 will develop a multinational collaborative research program related to the management of combat stress in the military. In general, this will involve identifying the kinds of situations warranting psychological support and determining the nature of that support. Topics to be studied include training in stress coping techniques and first aid for combat stress reactions (including self-help, buddy aid, and interventions by the military leader). Work is still in the preliminary stage; it is anticipated that reports of progress will be given at future IAMPS meetings.

Lt. Juan José Cerezo Ureta, a psychologist in the Spanish Ministry of Defense (Air Force), presented a general tutorial on the measurement of arousal (physiological, biochemical and psychometric methods), on the relationships between arousal and performance in the context of military operations, and on techniques for regulation of arousal levels (relaxation and activation strategies). He noted that work is in progress to train pilots in the reduction of arousal (both somatic and cognitive relaxation techniques), and that preliminary results are encouraging.

Lt. Col. Colman Goggin presented the results of an in-depth analysis of suicides in the Irish Permanent Defense Force (PDF) during the period 1974-1990. The average yearly suicide rate in the PDF was almost identical to the estimated national rate (approximately 13 per 100,000). Alcohol abuse, depression, and the copy-cat phenomenon were identified as major precipitating factors. The principal recommendations emerging from the study were the establishment of a comprehensive and multidisci-

plinary support network (involving medical officers, chaplains, and personnel support services) and the development of alcohol abuse, depression, and stress intervention programs.

Dr. Sarah Smith, a psychologist in the U.K.'s Army Personnel Research Establishment, reported on the results from a study of officers who chose to leave the Army prematurely, i.e., before the normal retirement date. Findings from an exit questionnaire that has been administered routinely since 1986 indicated no single major factor accounting for the departures; rather, a combination of reasons was most often cited. Insufficient job satisfaction, inadequate career development programs, and various lifestyle and domestic considerations were the most commonly cited concerns. Overall pay level was not identified as a major determining factor.

Dr. Milton Katz presented an overview of the mission and functions of the U.S. Army Research Institute (ARI) for the Behavioral and Social Sciences, with emphasis on ARI's European Science Coordination Office (ARIESCO), which he heads. In addition to performing a liaison function between ARI and military researchers outside the U.S., ARIESCO funds basic research that complements ongoing U.S. programs. Emphasis is placed on efforts that reflect different scientific approaches to the study of certain topics, and that would be difficult or impossible to conduct in the U.S. for various reasons. Examples of topics currently supported include performance under stress, terrorism, unit cohesion, and courageous behavior.

## CLOSING REMARKS

As can be seen from this summary of the symposium, IAMPS presentations typically cover a wide range of subjects. These include controlled laboratory experiments, field studies, preliminary inquiries, analyses, and tutorials. This variety reflects the diversity of the activities across nations and the amount of resources available for research and development. The value of this symposium derives not just from the exchange of scientific results but also from a sharing of experiences and lessons learned from diverse societies and cultures, most of which are facing similar challenges in an era of rapidly changing geopolitics.

I believe that military psychology is destined to play an increasingly important role, especially in those countries facing a period of force downsizing

and defense budget reductions. These factors will result in an increased emphasis on the efficient use of manpower resources, on the cost-effectiveness of training, and on the operability and maintainability of weapons systems. I am confident that IAMPS will continue to be a useful and informative forum in the coming years of turbulence and change in the armed forces of many nations.

With regard to future IAMPS agendas, the idea of identifying a special focus topic each year was well-received by the symposium participants and will be continued.

## REFERENCES

1. D.J. Hickson and S. Miller, "Concepts of Decision: Making and Implementing Strategic Decisions in Organisations," in *Leadership and Decision Making* (Cambridge University Press, Cambridge U.K., 1991), F. Heller, ed.
2. D.J. Hickson, R.J. Butler, D. Cray, G.R. Mallory, and D.C. Wilson, "Decision and Organization," *Public Administration* 67, 373-390 (1989).
3. C.J. Martin, *A Review of the Reliability and Validity of Computerized Tests Among RSG 15 NATO Countries*. (Draft paper) Department of the Navy, Washington, DC.
4. F.W. Steege and W. Fritscher, "Psychological Assessment and Military Personnel Management," in *Handbook of Military Psychology* (Wiley Chichester, 1991), R. Gal and A.D. Mangelsdorff, eds.
5. E.C. Webster, *Decision Making in the Employment Interview* (Eagle Publishing Co., Montreal, 1964).
6. E.C. Webster, *The Employment Interview: A Social Judgment Process* (SIP Publications, Schomberg, Ontario, 1982).
7. M.M. Harris, "Reconsidering the Employment Interview: A Review of Recent Literature and Suggestions for Future Research," *Personnel Psychology* 42, 691-726 (1989).
8. G.C. Homans, *The Human Group* (Harcourt, Brace & Co., New York, 1950).
9. M. Rosenbaum, "A Schedule for Assessing Self-control Behaviors. Preliminary Findings," *Behavior Therapy* 11, 109-121 (1980).
10. E. Svensson, M. Angelborg-Thanderz, L. Sjöberg, and M. Gillberg, "Military Flight Experience and Sympatho-adrenal Activity," *Aviation, Space and Environmental Medicine* 69, 411-416 (1988).
11. N. Moray, ed., *Mental Workload: Its Theory and Measurement* (Plenum, New York, 1979).
12. P.A. Hancock and N. Meshkati, eds. *Human Mental Workload* (Elsevier Science Publishers, Amsterdam, 1988).
13. D. Gopher and E. Donchin, "Workload - An Examination of the Concept," in *Handbook of Perception and Human Performance, Volume II*, (John Wiley & Sons, Inc. New York, 1986), K.R. Boff, L. Kaufman, and J.P. Thomas, eds.
14. H. Aschenbrenner and D. Wiegand, *Proceedings of the Workshop on Psychological Fitness* (Lahr, Germany, 28-29 Sept. 1988). NATO Document AC243/8-DS/A/DR(89), p. 107.

# Carbon-Carbon/Composite Assessment and Interpretive Report

by R.A. Meyer, Ph.D., Materials Department, University of California, Santa Barbara

## INTRODUCTION

A wealth of information is available about carbon/carbon composites (C/C) in Europe. American investigators must assess this valuable research information and use it to maintain the strong U.S. role in producing and applying C/Cs for future civilian and military systems. European organizations now have collective research capabilities for developing advanced C/Cs that could be equal to or better than those being considered in the U.S. Therefore, a significant impact is expected soon.

The collective research capabilities of the U.K., France, the Federal Republic of Germany, war-torn Yugoslavia, and the former U.S.S.R. encompass all of the important areas that are necessary to develop, manufacture, and apply advanced C/Cs. Sometimes the research is to a greater depth than that in the U.S. Certainly, the quality of the foreign research has improved with time. The effectiveness of these research activities is being enhanced, particularly in France, by excellent coordination between university, government, and industrial laboratories; frequent communication and collaboration between investigators is occurring on a national and international basis.

The C/C system is a unique material capable of use from  $< -160^{\circ}\text{C}$  to  $> 2,000^{\circ}\text{C}$ . Current and potential uses include but are not limited to:

- space shuttle ( $\sim 1,300^{\circ}\text{C}$ )
- substrates for chips ( $< 50^{\circ}\text{C}$ )
- hot structures for space planes ( $> 1,700^{\circ}\text{C}$ )
- space materials ( $< 90^{\circ}$  -  $> 200^{\circ}\text{C}$ )
- high-specific-impulse turbines ( $> 2,000^{\circ}\text{C}$ )
- antenna dishes (RT -  $> 1,700^{\circ}\text{C}$ ).

The full applications potential of C/C cannot be achieved without understanding how fiber-to-matrix bonding phenomena, or the influence of the microstructure of the matrix and other interactions actually change the physical properties of C/C. Department of Defense (DoD) organizations (such as the Office of Naval Research (ONR)) are sponsoring research to establish this information. It was recognized that their research efforts might be enhanced if additional

information were available from laboratories across the world.

As a result, ONR initiated a 4-month study on C/C composites research in Europe. The Office of Naval Technology, the Naval Surface Warfare Center, and the Air Force Materials Laboratory provided additional support. The study's goals were to evaluate the current status of C/C research, estimate its future directions, and determine the possibilities for collaboration. From the study, projections emerged about how these foreign research and technology efforts could affect related advanced C/C development and utilization. A companion study was conducted from the ONR Asia office in Tokyo. This overview assessment and individual reports of visits made in Europe as part of this study will be issued shortly in ONREUR Report 92-10-R, "Carbon/Carbon Composite Assessment Study and Interpretive Report."

## STUDY PURPOSE

This study was undertaken to evaluate the research capabilities and determine the activities of 16 organizations that are contributing to the information that can be used for developing and producing advanced C/Cs. These organizations are located in the United Kingdom, France, the Federal Republic of Germany (FRG), the former U.S.S.R., and Yugoslavia that are contributing to the information that can be used for developing and producing advanced C/Cs. Other objectives were to:

- determine what important C/C information is available to augment the research now being supported by DoD organizations;
- determine if opportunities exist for conducting joint research projects; and
- foster collaborative activities between foreign investigators and those in the U.S.

## WHY CONSIDER C/Cs AS A MATERIAL OF THE FUTURE?

The current utility of C/Cs is for specialized applications where high strength and stiffness proper-

ties are desired at elevated temperatures. Examples of such applications include dies and radiation shields for industry, gas diverter fins for aircraft, nosecone and leading edge protection surfaces for the space shuttle, and nosetips and exit cones for military purposes.

Other emerging applications for C/Cs include:

- artificial limbs and implants in humans, with high specific strength and inertness of carbon in the human body,
- substrates for semiconductors with high conductance,
- antenna dishes that utilize electrical conductivity and thermal dimensional stability properties, and
- radiator panels for space systems in which the high thermal conductivity provides a means of thermal management.

In the future, C/Cs will possibly be used for:

- turbines for aircraft engines
- hot structures for spacecraft and aircraft, and
- structural members and solar energy panels for space systems.

A concerted effort is underway throughout the world to find other applications for C/Cs. One obstacle is the lack of knowledge about a method for protection against oxidization in air at elevated temperatures. Another obstacle is the lack of how to develop the full potential of C/C's capabilities for meeting special engineering requirements where specific properties are required. Such improvements frequently require knowing how to economically refine and optimize processing conditions to get the desired physical properties. A significant investment in time, talent, and equipment is required to do more research. Thus, it behooves U.S. investigators to discover and understand the research activities that are being conducted abroad.

#### **FIBER DEVELOPMENT FOR USE IN PREFORMS**

Generally, all the organizations that were visited used fibers in their composites that were obtained from Japan or the U.S. I did not visit industry-sponsored fiber production facilities. In contrast, most of the research data comes from universities and government laboratories; these data form the basis for improving the capabilities of the fibers.

The former U.S.S.R. was independently developing, producing, and using its own fibers in C/Cs. Using rayon as the precursor, they began developing carbon fibers in the late 1950s. Today, other precursors include PAN and pitch. The tensile strength and modulus values for PAN-based fibers are 5 GPa (725 ksi) and 200 GPa (29 mpsi), respectively. For the fibers from the pitch precursor, the values are 0.8 GPa (116 kpsi) and 100 GPa (14 mpsi), respectively. In today's industrial practices, these values are comparable to those of fibers that are used in C/Cs in other countries.

The former U.S.S.R.'s developmental goals for 1993 were PAN- or pitch-based fibers with tensile strength values of 7 GPa (>1.0 mpsi) and moduli of 300 GPa (43 mpsi). Based on these values, the strain values could be in excess of 2 percent, which would be comparable to or larger than the best values available in other countries. Without question, fibers made in the U.S. and Japan have strengths and moduli values that exceed the values of the former U.S.S.R. Therefore, Western countries are ahead technologically. However, there was a U.S.S.R. development program to close this gap. For optimizing their properties, this development appears to be concentrating on improving the purity of the precursors and using electrical measurements to characterize the fibers during and after processing. Future developmental programs appear to be directed toward obtaining fibers with high strain capability at the expense of obtaining very high moduli fibers. Such an approach can have distinct advantages for certain engineering applications, especially where toughness is required, e.g., exit cones for launch vehicles. Even if these U.S.S.R. goals are not completely achieved, the fibers now being developed should approach the mechanical property values comparable to Western countries.

No one in Yugoslavia was developing fibers. Consequently, they used fibers from other countries. A former prototype plant existed for making low modulus fibers from PAN. Whether it may be reactivated soon is problematical. The purpose would be to determine whether they can develop an inexpensive, low performance type of fiber for the world market.

In Western countries, many research and related technology activities are concerned with developing carbonaceous and graphitic fibers from pitch-based precursors and, to a lesser extent, fibers that come from PAN. The exact reasons for this emphasis is not known. One possibility is that much more is known about the PAN system and how to improve

the quality of the fibers derived from this precursor. Another possible factor is that this fiber is being successfully used throughout the world. Therefore, most of the research is sponsored by the producers. Because they do not make their findings public, other researchers are reluctant to enter this area since the proposed research may have already been done. Consequently, industry and government are funding only a limited amount of additional research to improve the physical properties of pitch-based fibers.

Universities also receive limited funds for investigating new fiber concepts. In contrast, the pitch system is not as widely used in the world market because it is more expensive to produce compared to PAN-based fibers. Therefore, a real incentive exists for conducting research to understand the fundamental reasons for improving the processing procedures and lowering costs or to upgrade the fiber's properties. Several industrial firms in Europe and Asia are giving small grants to universities to conduct exploratory research with the hope that new approaches and solutions can be found.

The purpose of research for different pitch systems is to understand the mechanisms that cause the formation of various types of microstructures and physical properties in carbonaceous and graphitic fibers. For example, *high modulus and strength* values observed result from the well-aligned layer planes of graphite that make up their structures. These may be planar or crenulated and have radial, concentric, or other orientations as viewed in the transverse sections of the fibers. Their different microtextures depend on the source of the fiber's precursor (usually coal or petroleum pitches) and the processing conditions. The sequence of formation of these microtextures is complex because of the many different chemical compositions and their interaction with each other as the heat treatment proceeds. However, understanding this phenomena is important if specific types of microstructures are to be produced in the fibers. As a result, many investigations are under way to determine the compositions of different pitches and how they are affected by different pyrolysis conditions.

Rheological and viscosity characteristics influence the flow characteristics of the pitch as it passes through the orifices during the spinning operation. Extensive studies are under way to understand the nature of the microtextures that are developed during spinning. For example, microtexture depends on the degree and distribution of isotropic and anisotropic pitches in the total pitch system. Furthermore, micrographic analysis has shown that during spinning,

sharp interfaces exist between these phases. When fibers are heated to graphitization temperatures, the anisotropic phase will be highly oriented. Conversely, the isotropic phase will show a poor degree of orientation. The different combinations of these phases within fibers result in variations of the fiber's microstructure, which is important in determining its mechanical properties. Normally, only tensile properties are determined on single fibers. This tensile evaluation is limited because compressive strength is equally important.

Recently, a novel method has been used for determining single fiber compressive properties. This procedure eliminates uncertainties in these values. Until now, a fiber's compressive strength value has been defined based on theoretical calculations of how single fibers have contributed to the experimentally determined strength of a unidirectional composite that contains thousands of fibers. This new testing capability is important because it gives accurate compressive strengths that will help overcome a major limitation in the applicability of the high modulus pitch-based fibers.

Many organizations in Europe are making significant and sometimes unique contributions toward understanding the complex phenomena that takes place during the forming and processing of these fibers. With these capabilities, these research organizations can make recommendations for improving the fiber's properties.

## WEAVING OF PREFORMS

Outstanding weaving efforts are being undertaken at Aérospatiale and at Société Européenne de Propulsion (SEP). At Aérospatiale, there are three-dimensional (3-D) weaving apparatuses for constructing C/Cs that contain different types of fibers. Procedures have been developed using these looms so that preforms can be automatically woven into various shapes with different thicknesses. The shapes range from nosetips to integrated throat and entrance (ITE) pieces for rocket engines. Other methods have also been developed at Aérospatiale for weaving C/Cs with as many as seven orientations and containing fiber densities up to 60 volume percent. The locations and angles of the yarns, including the spacing of pins on the mandrels, are all determined by computer-aided analysis. Some of this weaving equipment and the weaving methods have been sold to U.S. industrial organizations.

The SEP organization also can weave and lay up different configurations with 3-, 4-, 5-, 7-, and even 8-D orientations. Equipment can now process pieces

as large as 4-m diameter. This organization has developed a unique, generic type of C/C preform composed of layers of 2-D cloth held together by needling with yarns in the third dimension. When fully processed, this type of C/C is called Novoltex®. This construction is being used to fabricate all sorts of C/Cs with different thermal and mechanical properties for use in many different applications. For example, it is being used for making exit cones with diameters that exceed 1,400 mm. The expectation is a value of 2,900 mm for boosters that could be used in 1992 for the Ariane 5.

Between the Aérospatiale and SEP organizations, capabilities exist for designing whatever architectures are desired, and weaving them into configurations required now and in the future. It was not possible to determine what types of research are being conducted in these organizations for improving analytical methods or weaving capabilities.

#### METHODS FOR DENSIFYING PREFORMS

The next step in fabricating C/C composites is to densify the woven preforms by impregnation methods using either liquids or gases to fill the voids between the fibers and yarns. Impregnation is followed by heat treatment to form a carbonaceous matrix around each fiber and between the yarns. Usually, the impregnation and heat treatment cycles must be repeated several times to get the desired densities of the C/Cs. Their physical properties are determined by the fiber-to-matrix interactions, which in turn are controlled by the microstructure of the matrix (whether the preforms are permeated with liquid or gases).

Consequently, it is important to understand what mechanisms control the formation of the necessary microstructures so the C/Cs desired properties can be acquired and to utilize the mechanical properties of the fibers. Today, even after more than 25 years of making C/Cs, this utilization factor is usually less than 65 percent, far less than for other noncarbonaceous matrix types of carbon fiber composites. It is possible to improve the properties of C/Cs provided the proper types of matrix microstructures can be identified and produced. Therefore, many research activities are being undertaken to achieve better performance of C/Cs.

The liquid impregnation method is a major procedure to densify C/Cs. The liquids used are normally derived from organic precursors like a phenolic or from pitch that is derived from coal or oil. In general, pitch is preferred because a larger variety of microstructures can be derived from it.

The conversion of pitch to carbon takes place by a process of pyrolysis where low molecular weight species evaporate as the temperature is progressively raised. At higher temperatures (350-425°C), cracking reactions occur, followed by the evaporation of volatile fragments that mainly result from the thermal scission of aliphatic side-chains to polycondensed aromatic ring structures. The polynuclear aromatic radicals produced are quite reactive. They combine to form planar aromatic ring structures of even higher molecular weight and aspect ratio. These will have an influence on the pitch's viscosity and rheology, which in turn will determine how well the pitch enters and impregnates the woven preforms.

As pyrolysis is continued, these planer ring molecular structures occur, and the liquid or mesophase state of the pitch system develops. At this stage, the ultimate microstructure of the matrix is determined. For this reason, a lot of research is being directed toward understanding the nature of these pitch systems.

A major area of research interest is whether the pitch is in a liquid crystal or colloidal state at the mesophase stage. An optimum microstructure of the matrix, as well as that of fibers, can be obtained by selecting the type of pitch and using specific procedures of heat treatment. Many investigations are concerned with the chemical composition of these mesophase systems and how chemical additives influence the polymerization, carbonization, and graphitization steps to control the grain size and orientation of the matrix microstructure. In this discussion, microstructure means inclusion of the pores and cracks that exist in C/Cs.

Significant research is being undertaken to study the degree of bonding, fiber strength, and toughness values for these materials. Controlling the size and distribution of the pores can have a profound influence on the mechanical properties of C/Cs. The concentration of pores can be altered by proper heat treating and used to increase their toughness values. Cracks can be distributed either within the matrices or at the interfaces between the matrix and the surfaces of the fibers or yarns.

The second major procedure for the impregnation of C/Cs is to deposit the carbon by the chemical vapor deposition (CVD) method on the walls of pores in the interior of the preforms. Clearly, this method has the best ability of filling pores that are too small for liquid pitches to enter. However, a major consideration is to ensure that the carbon is deposited uniformly throughout the thickness of the preforms. Consequently, special attention must be given to the processing conditions, and to the fixtures

that hold the preforms in the deposition furnaces. For large pieces like exit cones, the problem of obtaining uniform densities is not trivial. Errors can be very costly. Therefore, Aérospatiale is investigating how to predict and select the proper processing conditions the first time the cones are processed.

Research is also being conducted to understand how gases diffuse through the various types of pore distributions in preforms. Also being investigated is how to enhance the rate of carbon deposition at lower normal deposition temperatures in which the deposition gases are passed through a high-frequency electric field.

Capabilities exist in Europe for the densification of all types and sizes of C/Cs. Furthermore, these capabilities are being guided by research that is concerned with

- the nature of the liquid or gaseous precursors;
- the interaction that controls the type and distribution of the matrix microstructure that evolved through using different processing conditions; and
- how this matrix interacts with the fibers/yarns that it surrounds.

#### **CHARACTERIZING C/Cs AND OPTIMIZING PROPERTIES**

The physical properties of C/Cs are determined by the type and architecture of the fibers and how these are bonded by various kinds of matrices in each type of preform. To be able to select the optimum combinations of processing conditions, property measurements must be available to properly evaluate the performance of the C/Cs, constituent parts as they are being subjected to mechanical stresses. The usual practice of characterizing C/Cs is indirect in that their mechanical properties are measured and then correlated with any variations.

Sometimes the microstructure of test samples will be examined by optical or SEM methods after they have been fractured. Now more detailed fractographic investigations are being conducted in this research by using acoustic emission techniques while the samples are being tested. Also, image analysis methods of the microstructure are being used to compare changes before and after samples are tested.

The next advance in characterization methods will be real-time, in situ observations of the fracturing behavior in the C/Cs as they are being stressed. This capability is needed to get a true appreciation of the fracturing sequence. However, this type of

characterization is not being done at this time on C/Cs, but a method and the necessary equipment have been developed for observing the in situ fracturing behavior of ceramics. There should be no problem in substituting C/C samples for ceramic ones. This would enhance the conducting capability in-depth research about the relative importance of the microstructure to the crack propagation characteristics. Details of the crack distributions and any changes of the microstructure of the stressed samples are best revealed with the SEM. In preparing the samples, the usual metallographic polishing etching techniques are used.

A major attribute of C/Cs is their ability to be stronger than any other material at temperatures above 2000°C. But under this condition, the deformation characteristics of C/Cs are expected to be different than at lower temperatures. The Deutsche Forschungstätt für Luft und Raumfahrt (German Aerospace Research Establishment [DLR], Cologne) is conducting this research. They are developing a method and preparing the necessary equipment for making tensile measurements at temperatures of more than 2200°C.

The optimum properties of C/Cs can be obtained more quickly and economically by understanding the microstructural factors that control the fracturing behavior. This is best achieved by using the combination of experimental data and theoretical analysis to select an optimum type matrix microstructure. Only a small amount of this kind of research is being conducted. Another approach is to predict theoretically and verify experimentally the influence of microstructure on the electrical properties of C/Cs.

This same microstructure will also determine the mechanical properties. Therefore, both of these properties can be optimized by the electrical measurement. If the desired microstructure can be predicted analytically, it should be possible to develop new materials cheaper and faster, provided the process conditions are known for producing specific types of microstructures. In addition, this type of research will help develop procedures to control the quality of C/Cs, and therefore increase the production yields.

The capabilities found in these organizations for conducting nondestructive evaluations (NDE) of C/Cs consist of X-ray and ultrasonic procedures. I found no information about advanced technology such as computer-aided tomography, thermal mapping, or other advanced techniques. This is a surprising situation, especially for large and advanced organizations like SEP and Aérospatiale. Perhaps

these organizations do not believe such advanced techniques are cost effective.

Important research programs are being undertaken to determine the contributions of the constituents of C/Cs to their physical properties. As a result, optimum processing procedures can be selected to obtain the desired engineering properties. Apparently, the NDE capabilities in these countries are adequate for production purposes.

### PROTECTING C/Cs AGAINST OXIDATION

Protecting C/Cs against oxidation at high temperatures is a major factor in maintaining their mechanical properties. Although research into oxidation and its suppression is not an objective of this survey, I include this information because it is important to the future applicability of C/Cs. Several organizations that I visited are concerned with the interaction of, or methods for, inhibiting oxidation effects in C/Cs.

Silicon carbide (SiC) is the material normally used to coat C/Cs to protect them from oxidation. Major problems are the differential thermal expansion coefficient and the resultant effects between SiC and C/Cs. These cause cracks to develop in the coating as it is thermally cycled and reduces its protection ability. Therefore, current R&D efforts are attempting to overcome the cracking problem by applying more than one layer of coating.

One example is a three-layer system composed of an outer layer of aluminum oxide ( $Al_2O_3$ ), a middle layer of aluminum nitride (AlN), and finally SiC deposited on the C/C. Schunk Kohlenstofftechnik developed another example of three layers. This system has an inner layer of SiC that is converted from silicon oxide ( $SiO_2$ ) and a middle layer that is formed by the deposition of pyrolytic carbon. This middle layer is a transition layer to absorb the differential expansion effect (it is allowed to crack during the thermal cycles). The third and outer layer is  $SiO_2$  glass whose purpose is to inhibit the diffusion of oxygen into the composites. Efforts are under way to explore the feasibility of depositing oxidation-resistant layers more economically by using the sol-gel method and a combination of SiC and silicon nitride (SiN) coatings.

Other research activities are also under way to understand the surface interactions between oxygen and the different types of carbons with their various microstructures and the interactions between the

carbon and the ceramic layers. The French government is sponsoring research on ways to inhibit oxidation effects.

### FACTORS ENHANCING EUROPEAN RESEARCH ACTIVITIES

Collectively in Europe, the capabilities now exist for acquiring the necessary information to develop advanced C/Cs. In the future, these collective capabilities should significantly influence the utilization and production of C/Cs throughout the world. This expectation is made on the basis that these European countries can concentrate and coordinate their R&D efforts more effectively because the U.K., France, and FRG (the leaders in C/Cs) may soon join some of their C/C R&D activities under the environments developing in Europe. Furthermore, the former U.S.S.R. (another leader in C/Cs), and Eastern/Central European countries are moving toward the European Community in their desire to export their own technology and materials. The major concern is how well the capabilities of these countries can be integrated into effective R&D programs. A certain amount of duplication of effort naturally occurs between the different countries. The duplication is partially mitigated because there is usually a difference of interest and expertise, even in the same research areas.

Other nontechnical factors are being used to enhance the collective research capabilities of these countries. These factors include:

- Communication links that are well established and frequently used between investigators, organizations, and societies on national and international levels. For example, there are strong communication links within Japan and between France and Japan in the carbon and ceramic areas.
- Coordination of research efforts to ensure that they are complimentary for attaining the general objectives of the program. This is best illustrated by the reviews and planning sessions held annually in France between industry, universities, and government laboratories.
- Collaboration between different researchers and organizations on a national or international basis. A large source of information is available because most organizations want to collaborate with the U.S. The level of collaboration depends on the needs of the researchers. This may be as simple as exchanging of data, or more ambitious in nature

having visiting professors or graduate students. Sometimes these links for collaboration were established years earlier because many European researchers did their graduate work at a foreign university.

- Collection of research information is extremely important. Methods for collecting information vary. An efficient way is to invite a foreign expert to stay for several weeks, with all expenses paid by the host country. In recent years, many countries have increased their support of foreign travel because it is very cost-effective for obtaining research information.

These European countries are using the non-technical factors (communication, coordination, collaboration, and collection) more effectively than the U.S. to augment and enhance their research capabilities.

## EPILOGUE

The time that has elapsed since the site visits were made abroad has been valuable for checking impressions gained and expressed in this report. This assessment study contains information vital for the future of effective research in carbon-carbon composites. Its indication of unique efforts abroad and opportunities for cooperation with foreign counterparts are still accurate.

For the most part the directions of these foreign research programs continue. They were planned for years into the future and have some stability attached to them. This view was substantiated by recent discussions with investigators in Japan in March 1992 when I was a guest speaker at the Japan Ultra High Temperature Symposium, in China in April 1992 when I was there to discuss their carbon-carbon composite programs, and in Germany late in June when I attended the German Carbon Conference and visited three laboratories. Interestingly, the German carbon/carbon composite program is generally proceeding very well in the direction described in the body of this report. Some additional details are given below.

Of considerable interest in Japan is the recently initiated effort to identify and develop, within ten years, C/Cs that could be used for constructing combustion chambers and turbines for a direct hydrogen-oxygen cycle system designed to operate at a maximum temperature of 2000°C and a pressure of 100 atmospheres. Their goal is to provide a high efficiency thermal cycle for the production of power without any contamination to the atmosphere. In support of this program, the Japan Ultra-high Temperature Research Center has just been activated at Yamaguchi. This facility is a government-supported national project for processing and characterizing materials at temperatures in excess of 2300°C by using specialized equipment that cannot be afforded by any single corporation or organization.

The most recent discussions with researchers in China have made it increasingly apparent there is more emphasis and sensitivity here than in any other country, to the importance of matrix microstructure and fiber matrix interactions and their influence on thermal mechanical properties of C/Cs. Probably close to a hundred scientists and engineers are working in this area. Through such an understanding it should be possible to obtain the maximum utilization of the fiber properties and therefore to produce superior C/Cs. A compilation, with a Chinese text, containing more than 150 pages of various types of microstructure that have been observed in C/Cs over the past ten years has just been completed. The English version should be available shortly.

At the German Aeronautical and Astronautics Laboratory, a new procedure has been developed that permits, for the first time, quantitative image analysis by digitally processing the microstructure of the carbonaceous matrix that surrounds the fibers, as observed with the TEM. With this method it is possible to define the degree of graphitization within 0.05 angstroms as well as the distribution of voids, cracks, and the degree of chemical bonding. This should greatly assist the understanding of processing conditions and their influence on the microfracturing behavior of C/Cs.

# Chemistry

## Nonequilibrium Chemical Dynamics: From Experiment to Microscopic Simulations

by D.T. Gillespie, Research Department, Naval Weapons Center, China Lake, California

### INTRODUCTION

More than 2 decades ago, Belousov and Zhabotinski injected new life into the field of chemical kinetics with their experimental discovery of limit cycle behavior in a stirred chemical reaction. Since then, the study of temporal and spatial patterns in open, nonlinear chemical systems has been a great adventure in chemical physics, both experimentally and theoretically.

The Nonequilibrium Chemical Dynamics: From Experiment to Microscopic Simulations meeting was held in Brussels, Belgium, in December 1991. The meeting was simultaneously a NATO Advanced Research workshop and a Europhysics (EPS) Liquid State Conference. The host institution was the Center for Nonlinear Phenomena and Complex Systems at the Free University of Brussels (ULB). Profs. Prigogine and G. Nicolis presented opening addresses. Both are from ULB and the latter was responsible for the direction and energy of this meeting.

Much of the leading research in this area is currently being carried out by the participants at this conference, so work reported on provided a look at the current state of the art in nonequilibrium chemical dynamics. The site of the conference was especially appropriate since the first two-variable limit cycle reaction model (the "Brusselator") was invented here in the 1960s by Prigogine, Nicolis, and Lefever.

I mention only the highlights of the workshop as I perceived them, cautioning the reader that even though I did give one of the invited papers, this is not my main area of expertise. Full details may be gleaned from the workshop proceedings, which is scheduled to be published as a special issue of *Physica A* (tentatively, the 1 September 1992 issue).

### PRESENTATIONS

A dozen experimental papers were presented, and they unquestionably were the real attention grabbers. Anyone who thinks that chemical kinetics consists merely of following a monotonous approach to some uniform, quiescent equilibrium state will scarcely believe the stationary hexagonal and striped concentration patterns arising in the open gel-filled reactors of P. DeKepper's group in Bordeaux, France, and H. Swinney's group in Austin, Texas. These spatial patterns are ascribed to a Turing-type reaction-diffusion symmetry-breaking instability; they are referred to as "Turing structures."

Swinney's group has shown controlled transitions from a uniform concentration state to both striped and hexagonal concentration states, as well as to multiple wavelength domain states and turbulent states. S. Müller, Dortmund, Federal Republic of Germany (FRG), has studied the two-dimensional rotating spiral waves of the Belousov-Zhabotinski reaction, concentrating on the intricate patterns traced out by the center tip of the spiral.

J. Micheau and coworkers in Toulouse, France, reported the first example of photochemical bistability in a continuously stirred tank reactor (CSTR). J.P. Laplante of Kingston, Canada, summarized his recent experimental studies of the "front propagation" of a stable state transition using a chain of 16 coupled CSTRs. Other research described included the wide-ranging work of I. Epstein and coworkers in Waltham, Massachusetts, to discover new chemical systems that exhibit pattern formation, and the interesting work of D. Luss, Houston, studying temperature waves on catalytic surfaces.

The challenge to mathematically model the richly diverse behavior of open, nonlinear chemical systems is clearly irresistible; most of the other papers at the workshop were aimed toward this end.

These papers fell into three broad categories. The first, analytical and numerical studies, aimed specifically at modeling Turing structure behavior. These works included studies of

- coherent structures in the Ginzburg-Landau equation,
- resonance forcing of spatially distributed chemical oscillators,
- how hexagons and stripes arise from solutions to the Brusselator reaction with diffusion, and
- stripes, hexagons, and zig-zags in a variant of the Brusselator with diffusion.

These studies were carried out by workers in France and Belgium.

The second category of theoretical papers focused on microscopic simulations. J.-P. Boon, ULB, and R. Kapral, Toronto, both showed how Turing structures can be obtained through a lattice-gas cellular automata model of the reaction-diffusion equations. M. Malek Mansour and F. Baras, ULB, gave an overview of microscopic simulation schemes for complex chemical systems.

My own talk concerned the modeling of a well-stirred chemical system in thermal equilibrium, showing in detail how the microphysics implies that such a system can be rigorously viewed as a jump-type Markov process. Also falling into this category was the presentation by C. White, Naval Research Laboratory. White reported on his impressive molecular dynamics simulations of a model shock-wave detonation reaction.

The third category of theoretical papers might be called unconventional kinetics. One of the most fascinating of these is the work of A. Arneodo, Bordeaux, France. He reports the discovery of Fibonacci sequences in the structure of diffusion-limited aggregation (DLA) clusters; he has used wavelet transform techniques to expose and inherent five-fold (snowflake) symmetry in the fractal geometry of these DLA clusters.

Two U.S. papers reported results of studies of the behavior of reaction-diffusion systems in less than three space dimensions. C. Doering, Potsdam, New York, presented results indicating that time-dependent but space-independent noise seems to induce spatial correlations in a simple one-dimensional model. K. Lindenberg, LaJolla, California, discussed kinetic anomalies and pattern formation in one- and two-dimensional systems, as well as for some fractional-dimensional (fractal) lattice systems. These various low-dimensional effects apparently arise because diffusion is not an efficient mixing mechanism in less than three dimensions. Finally, I mention the development of K. Showalter and co-workers, Morgantown, West Virginia, of a simple proportional feedback algorithm for controlling (i.e., reducing) low-dimensional chaos.

#### CONCLUDING COMMENTS

The life sciences will probably be the first beneficiaries of these research efforts. The work represents an undeniably fascinating and challenging thrust into the unknown. Apparently, it has attracted much of the current top talent at the interface area between chemistry and physics.

## Computer Science

### The Fifth European Seminar on Neural Networks and Genetic Algorithms

*by J.F. Blackburn. Dr. Blackburn is a former Liaison Scientist for Mathematics and Computer Science at the Office of Naval Research European Office. Now retired, he is a consultant to the Microelectronics and Computer Technology Corporation, Austin, Texas.*

#### INTRODUCTION

At the Fifth European Seminar on Neural Networks and Genetic Algorithms, held in London,

on February 12-14, 1992, ten papers on neural networks were given. Speakers on neural networks came from the United States, France, Germany, the United Kingdom, and Korea. Several of the

presentations are described below; my comments follow.

## "MARKET UPDATE"

In 1975, before the term Neural Networks had come into use, Nestor, Inc. began work on finding applications for neural networks. Simon Heifetz, Vice Chairman, Nestor, Inc. (United States) provided a "Market Update."

In the beginning, there were grandiose visions of the possibilities. One of the earliest applications was for character recognition. By 1985 a system for recognizing thousands of Kanji characters had been developed. Digital Equipment was interested in this development for implementation in microprocessors but shortly afterward withdrew from the microprocessor development effort.

Beginning in 1986, "applications" began to be reported in research papers and at conferences. They were publicized by tool-kit vendors but lacked rigorous measures of performance. A fairly comprehensive list of applications was developed including: Kanji handwriting input for personal computers, English and French handwriting computer inputs, target recognition in sonar image, and speech recognition.

By 1991, in-house systems were in existence but, lacking robustness, they were used and maintained by their developers. Some robust and complete systems were developed on a custom basis by vendors. Application-specific recognition modules were offered for incorporation into commercial products. The most important applications were for pattern-recognition systems.

The hope was that neural networks would make computer programming obsolete. The hype arose that development tools would be able to virtually automate the development process. Neither the hope nor the hype has been realized, and the likelihood of its becoming so seems dim for the near future.

However certain strengths of neural networks still make them applicable and useful for many applications. By generalizing from a few examples to concepts, some neural networks can avoid the creation and maintenance of large sets of rules to describe the variability in data. Unlike statistical models, some neural networks can map complex nonlinear boundaries in pattern space without attempting to fit the data to an explicitly proposed function. Some networks can adapt readily to pattern sets that are highly variable or that change over time. Field trainability enables systems to be designed that can be

updated and maintained by relatively unskilled operators.

As adaptive pattern recognition systems, neural networks learn to associate features of patterns with classes, and they learn by example during supervised training. They are trained on data, rather than knowledge engineered. They store their knowledge as trained feature memories, not as explicit rules of decision trees. Importantly, they solve problems where it is difficult to define rules.

Expert systems require complete codification of expertise, and stored knowledge is inflexible, difficult to change. Such systems are used only for small knowledge domains; they do not scale-up well. They are slow and ineffective for pattern recognition.

Neural networks have more in common with statistical models in that both are data-driven and adaptive. Neural networks are based on formal, parallel architectures of computational elements and do not assume any prior model. They can develop highly complex models to describe data, and knowledge is stored as weights in the model.

Statistical models normally must be fitted to some prespecified analytical function and can be cumbersome to use in mapping nonlinear, multivariate interdependencies. Knowledge is stored as parameters of a function.

Not all neural networks are alike; they differ in their ability to learn rapidly, to generalize, to discriminate, and to scale-up to large problems. Neural networks have some weaknesses. They may require larger training sets than statistical models, and performance is limited by quality, consistency, and quantity of training data. Much development time is devoted to data representation, and automatic feature extraction has so far been disappointing.

Public domain networks, such as backward propagation models, are configured by trial and error, since there are no guidelines for configuring the hidden layers of these systems. They do not scale-up well to large problems. As the number of inputs increases, computational complexity grows and training time grows. A possible solution is to decompose the network into simpler subassemblies of simpler networks.

A complete custom solution to a problem is usually a hybrid system, combining a variety of tools and techniques. The data requirements for custom solutions include a sufficient number of training examples, data that is relevant, data integrity and consistency, and a balanced training set. Testing requires unseen data, a sufficiently large test set, and natural distribution.

## "NEURAL NETWORKS: RESEARCH AND CURRENT COMMERCIAL TECHNOLOGY"

Professor David Bounds, Aston University, U.K., discussed "Neural Networks: Research and Current Commercial Technology." He noted that neural networks have now reached the stage where they are generating commercial benefits for companies across a broad spectrum of business. Companies who are benefitting have little incentive to broadcast the sources of their competitive advantage, and the specialist companies who are supplying solutions to corporate clients are often unable, or unwilling, to discuss their business. This low visibility does not mean that neural networks are not delivering the goods.

The main opportunities for exploiting neural network solutions to problems are in: data-rich environments, nonlinear processes, areas where conventional statistics are inappropriate, and unexplored territory. In financial services, applications that are being successfully addressed include database marketing, direct marketing through mailslots, media planning, and customer analysis.

## "NEURAL NETWORKS: OPENING THE BLACK BOX"

Neural nets for planning and decision support are being developed, showing their value in economics. Dr. H.G. Zimmermann, Senior Researcher, Siemens, Germany, discussed "Neural Networks: Opening the Black Box." On the one hand, these techniques draw their analytical power from general mathematical principles that are not directly based on fundamental principles in economics. This includes the possibility for modeling multidimensional nonlinear connections and learning by example. On the other hand, there are neural models that can be followed back to their roots with an economic interpretation. For example, certain neural networks with feedback can be viewed as an interaction model of decision-makers.

Following much theoretical work, in the period 1943 through 1986, the theory of neural networks experienced further impulses for development because it represents an extreme realization of the idea of parallel processing, which in computer science is being developed as an alternative to the Von Neumann computer. On the software side, neural networks offer an alternative to the construction of expert systems.

In the first part of this paper, the relevance of the Multi-Layer Perceptron (MLP) for data analysis

was worked out. The advantages of this model are based on its possibilities to represent, in closed form, multidimensional nonlinear structures. Currently, most applications are carried out worldwide with this model.

## The Multi-Layer Perceptron

In the MLP model, each neuron can have many input channels through which pulses, represented by real numbers  $x_i$ , enter. Upon entering the neuron, these pulses are distorted. This is accomplished by multiplication with the weight  $w_i$ . If in the product  $w_i x_i$  the weight is a number from the interval (0,1), the input pulse is flattened. If the weight is greater than 1, the amplitude of the corresponding input pulse is increased. If  $w_i$  is a negative number, the incoming pulse results in a diminution of the other incoming pulses. From these weighted impulses, a superposition is formed through summation.

Further processing in the neuron depends only on this total pulse. In the next step it is compared to a threshold value  $T$ . If the threshold is exceeded,  $\text{Summation } w_i x_i - T$  is positive, otherwise it is negative. The following nonlinear function acts like a switch. If the threshold is exceeded, the starting value of the neuron is pushed to an upper bound (here 1), otherwise to a lower bound (here 0). In the model above the nonlinearity has the form of a smoothed step.

For the mathematical expression of such a nonlinear function a logistical function of the following form is often used:

$$f_t(v) = (1 + e^{-v/t})^{-1}.$$

The parameter  $t$  controls the gradient of the graph in the middle region. For large  $t$ , the gradient is very small, for  $t$  approaching 0, the curve approaches a discontinuous step function.

The topology, that is the graph structure, of this network is that of a directed, layered graph, in which the nodes on the left side serve for the input of real numbers as input to the system. From there the inputs travel to a layer of neurons. Their output serves as an input to the next layer of the network. The output of the last layer serves as the output of the total system.

Corresponding to the topology described above, the dynamics of this network represents a direct information flow through the network graph. By writing the input pulses into a vector and denoting the output pulses of the  $i$ -th layer by the vector  $x^i$ , the network dynamics can be understood as a

chaining of nonlinear mappings. Viewed formally, the multilayer structure represents a nonlinear mapping of

$$x^p \text{ into } x^m.$$

This nonlinear assignment again is built up by an alternate chaining of linear and nonlinear mappings. If the nonlinear terms were dropped, the leftover chaining of linear mappings could be comprised into a single linear mapping. If, on the other hand, the matrix operations were canceled, the pulses appearing in the vectors would not be mixed, and only a parallel execution of one-dimensional nonlinear functions would result.

### Evaluation of Neural Networks

Neural networks can be compared with expert systems. For an expert system, the problem definition has to be investigated by a human expert. Through experience with the topic, the expert acquires an understanding of the structure of the domain. This understanding is transferred to a knowledge engineer and expressed in a rule-based system. The expert system can be composed from the above.

For a neural network, an observer obtains sample data from a domain to be investigated. This is not a simple process, because perceptrons describe only part of a reality. The sample data are then translated into the structure of a neural network by a learning algorithm.

In the neural network the structural analysis is done automatically, but for expert systems traceability of results is easier. It is true that neural nets can process problems without expert knowledge. This might lead to more objective results.

The question of just which problems can best be addressed by neural networks is not yet completely answered. The MLP and another method, the Boltzmann Machine, are well-suited for nonlinear time series analysis.

### "NEURAL NETWORKS FOR INDUSTRIAL VISION APPLICATIONS"

The European Commission-supported GALATEA project is designed to promote the application of neural networks in European industries. Sherif Makram-Ebeid, Laboratoires d'Electronique, France, described "Neural Networks for Industrial Vision Applications." Two applications have been selected to investigate the practical use of neural net software and hardware implementations in an indus-

trial environment. The applications are Surface Mounted Device Technology and Automatic Video Grading of oranges.

For the Surface Mounted Device Technology, the interest stems from Philips Industrial Electronics Division. They manufacture automated systems for mounting surface-mounted devices (SMDs) on printed circuit boards (PCBs) at high speed (typically 36000 components per hour). The ever-increasing number of components brings down the overall fabrication yield so that corrective actions are frequently required. The current technological trend is for further miniaturization of components. The project objective is to develop robust neural net implementations of computer vision functions that should improve fabrication yields.

The second industrial vision application within GALATEA is for the Orange Videograding. The industrial interest stems from Consorzio per la Ricerca (CRAM) in Agricoltura nel Mezzogiorno, Italy. The purpose is to develop a robot for sorting oranges automatically according to the type and number of defects on their surfaces. Currently, no system can provide a totally satisfactory solution. CRAM collaborates with Philips-LEP on this project.

### "LINNET DEMONSTRATOR FOR LONDON UNDERGROUND"

Chris Cox, Engineer, London Underground Ltd, described the "Linnet Demonstrator for London Underground Ltd." Following the recommendations arising from the Fennel Report after the Kings Cross Underground Station fire, London Underground Ltd has carried out an accelerated program of equipping stations with a range of communications equipment. This includes a vast network of closed-circuit television (CCTV) cameras for monitoring safety and security. The Station Operations room is the central control point for the station and is continuously manned while the station is open to the public. Much of the work in the stations involves crowd control, which is particularly important in the confined space of the often-overcrowded stations.

At times of service disruption or difficult operating conditions, it can be difficult for the operator to adequately monitor all the data available from a multitude of sources, including six TV monitors from which a selection of 30 or more images can be viewed. Some method is needed to filter and prioritize this information. It was thought that neural networks might offer a possible solution, and this application was proposed for a neural network demonstrator.

## The Demonstrator

The purpose of the demonstrator was to validate the ability of a neural network to classify the concentration of passengers on Underground station platforms by using existing CCTV images. The planned approach was to explore the performance of two different neural network algorithms: the Multi-Ram Discriminator and the Multi-Layer Perceptron. Conventional image processing methods were also explored.

Video tapes from a Northern Line platform and a Central Line platform were edited by London Underground Ltd staff to provide data that were coarsely divided into appropriate categories. Selected frames from the edited tapes were digitized by conventional means to yield  $256 \times 256$  pixel images, each pixel having one of 256 possible intensity values (gray scales).

### Multi-Ram Discriminator

With the Multi-Ram Discriminator the input is mapped onto random access memory (RAM) and patterns of memory bits (known as n-tuples) are arranged to randomly sample the input image. Multiple classes of images can be recognized by a group of Single RAM Discriminators to form a Multi-Ram Discriminator (MRD). The MRD has the advantage of rapid learning, simple implementation, and the possibility of forming large networks. The MRD was trained on 20 images from each class and then tested on 80 images from each class.

Measurement of the performance of the networks was calculated using the overall percentage of correctly classified images, and the average discrimination or confidence level of the output. The MRD achieved an overall performance on the images from the Central Line platform of 97%.

### Multi-Layer Perceptron

The MLP was tested by using the back propagation training algorithm. Three preprocessing techniques were used: a normalized intensity histogram, a frequency analysis of the image using Fast Fourier Transforms, and simple subsampling. The preprocessed image was then fed to the network. A sigmoid was used as the node transfer function, and

the connections were randomly weighted on initialization.

The network was found to operate best with a hidden layer of just four or five nodes. For the Central Line platform, 94% of images were correctly classified. However the MLP showed wide variations in performance depending on the method of preprocessing used.

Two conventional image processing techniques were tried, achieving results of 90% and 80% respectively. On the basis of the study, it is evident that the neural approach to image classification is at least comparable to the conventional approach adopted. London Underground Ltd plans to continue to explore the feasibility of using neural computing in this and similar applications.

## COMMENTS AND ASSESSMENT

Although no company has indicated willingness to bet its future on neural computing, a very large number of companies and other organizations are experimenting with a fairly wide number of applications.

The types of applications with which most of the successful experimentation are being done involve pattern recognition or scene analysis. The character recognition experiments range from a bomb sniffer using spectrographic analysis to intelligent character recognition for postal sorting. A good example of the scene analysis capability is that of the classification of crowds of passengers on the platform of the London Underground.

Another application that is meeting with considerable experimental success is that of credit scoring in the financial services industry. A fairly sizable number of representatives from this industry were in attendance. Neural networks also offer the possibility of providing decision support in other applications in the financial industry and in other industries as well.

An important attraction of neural networks as contrasted with expert systems is its nondependence on an expert in the particular application under study. However, expertise in the use of neural network systems is required. This expertise can be transferred from industry to industry and from application to application.

# Materials

## Polymers in a Marine Environment

*by Joseph H. Magill, Liaison Scientist for Polymeric Materials for the Office of Naval Research European Office. Dr. Magill joined ONR Europe from the University of Pittsburgh, Pennsylvania where he held Professorships jointly in Materials Science and Engineering and in Chemical and Petroleum Engineering.*

### INTRODUCTION

The Third International Conference on Polymers in a Marine Environment was held 23-24 October 1991 in the Institute of Marine Engineers Conference Center, London, U.K. It was sponsored in part by the Office of Naval Research.

Eighteen papers from twelve countries were presented. These papers described

- recent developments in composite materials for ship and off-shore applications;
- their behavior in fire test situations, with emphasis on their mechanical integrity and durability;
- electrostatic build up induced by liquid flow in composite nonconducting pipes. (This may cause sparks and hence fire hazards);
- corrosion of metallic structures and fittings; and
- antifouling coatings for drag reduction associated with seagoing vessels.

### OVERVIEW

The Navy is interested in the ever-growing use of polymeric materials in hostile environments—both the advantages and disadvantages of their use. This report is the writer's overall assessment of the status of the field at this time.

Rear Admiral M.A. Vallis, President of The Institute of Marine Engineers, provided a brief and interesting background for the conference. He highlighted significant uses and requirements where polymers and composites have been increasingly used in ship and off-shore applications. In some instances these new materials have been used as substitutes for metals.

The remainder of this synopsis addresses some of the key issues and problems. Detailed papers, with discussions, have been published as proceedings

of the meeting. They are available from The Institute of Marine Engineers, The Memorial Building, 76 Park Lane, London, EC3R 7JN; approximate cost is \$130.

### POLYMER COMPOSITES

The use of fiber-reinforced (FRP) composites as pipes and panels for ships and off-shore applications was emphasized. State-of-the-art tests on land and at sea were used to evaluate these components. Sea trials were described during which polymer composites experienced up to storm-force 12 conditions and their performance was deemed to be satisfactory (they survived intact).

Various aspects of the behavior of these lightweight composites were also assessed during fire and blast protection tests. Fire resistance and material durability were addressed, but toxic hazards associated with the evolution of smoke and noxious fumes were not considered. Even with composite materials, burning or pyrolyzing\* in enclosed spaces, produces lethal carbon monoxide and other toxicants.

Except for the H120 test, which is covered in the British Specification Test No. 476 part 20, 1987, no American Society for Testing Materials (ASTM) or British Standard Specification (BSS) standards were emphasized. In the circumstances, one has to ask why established testing paradigms (universally agreed-upon protocols) are not available for testing composite materials for fire resistance and toxicity of degradation products; both factors influence proper assessment of a plastics performance.

### OTHER ITEMS

Again, test standards were not mentioned specifically for ropes and adhesive joints in wet and/or dry

\*Both of these processes occur simultaneously in a real fire situation.

environments. However, good engineering approaches appear to have been followed for evaluation purposes, even though specific tests were not mentioned! Even if the testing complies with good engineering practices, some kind of test standards should be applied. Gels for corrosion prevention were shown to be the answer for sealing and protecting metallic components (especially demountable fittings) in a marine environment. A recognized test procedure for evaluating corrosion should also be established.

The very important field of antifouling of docked ships is of major importance from scientific, economical, and environmental viewpoints. Fuel wastage associated with fouling/roughening of bulkheads is exorbitant, and the speed of vessels is considerably attenuated as well. In this area, there is a wide gap between environmentally sound performance goals and targeted performance goals, as several speakers noted.

Controlled release of natural biocides in the hull environment appears to be a positive step toward solving the fouling problem at this stage of development. A standard test has not been established at the present time for evaluating "easy-release," non-toxic paints.

## CONCLUSIONS AND RECOMMENDATIONS

In the opinion of the writer, standard test procedures must be developed if materials and performance evaluation is to be meaningfully carried out within and between different countries. We must establish standards so that we are able to work in association with many laboratories and test facilities. This cooperation is vital for effective technology transfer and materials evaluation in the U.K., U.S. and Europe—or indeed, around the world in our shrinking global situation.

This conference covered many aspects of polymeric applications for both on-ship and off-shore applications. The thermal stability of FRP composites was emphasized and shown to be superior in some respects to other materials, but the toxicity of combustion products was largely ignored. Procedures to combat or overcome corrosion were well addressed. Novel procedures for combating the fouling of ship hulls are encouraging. Here, too, an environmentally safe and universally effective test must be established.

Within the limits of testing, value judgments may still be necessary for polymers to be used when involving hostile environments. Even so, mature selection should be based on the best evidence available.

## Supramolecular Legos® and Other Things! Can We Mimic Nature?

*by Joseph H. Magill*

### INTRODUCTION

Supramolecular assemblies are ubiquitous in nature. Covalent and noncovalent interactions are basic in many natural complex polymers. We have much to learn from nature's "Lego® and abacus" techniques that result in well-designed molecular assemblies. Basic factors include molecular recognition and self-organization; environmental constraints are instrumental in the creation of biological systems. Can mankind use this *modus operandi* to synthesize polymers?

This challenge was adopted by some of the scientists who addressed the Specialty '91 Polymer Conference, held September 30 through October 3, 1991, in Mainz, Federal Republic of Germany. This

is one of the leading polymer science and technology conferences in Europe, and this year it was focused on macromolecular synthesis and properties. It considered strategies to produce supramolecular structures corresponding to dimensions on a mesoscopic scale and beyond. The program had a strong international flavor; 14 countries were represented, and invited speakers came from most of these. In addition to lectures, the meeting had approximately 60 contributed posters that were on display during the meeting.

Professor Gerhard Wegner, one of the Directors of the Max Planck Institut für Polymerforschung, emphasized the thrust of the conference, which addressed the diverse range of molecular architectures and attendant property features. These features

range from micro- (monomeric) to macromolecular and supramolecular moieties. He commented on the importance of the latter in nature and in man-made macromolecules.

This report does not cover all of the presentations (oral and poster); rather, it is selective—focusing on the most novel papers. There was very little overlap in the papers presented here and at the recent Biennial Polymer Physics Meeting, University of Leeds, September 9-11, 1991. Contributions made at the Specialty Polymer '91 Mainz meeting will appear as a special issue of *Polymer* (London), planned for publication in early 1993.

## SUPRAMOLECULAR SYNTHESIS

Professor Helmut Ringsdorf described the interaction of proteins and polymeric amphiphiles with lipid membranes. (This was different from the topic listed in the program). In his presentation he attempted to link life sciences and materials science, pointing out that the preparation of functionalized supramolecular (SM) systems was plausible, based on two important natural factors: molecular recognition and self-organization. The scenario is depicted in Fig. 1.

The chemistry of SM systems is developing as our ability to synthesize and characterize complex organic materials increases, but breakthroughs are slow, even with our present state of knowledge. In essence, Ringsdorf<sup>1</sup> emphasized that a pioneering approach in macromolecular synthesis is needed to make supramolecular systems—invoking the proper interplay between molecular self-organization and molecular recognition. In the latter, order and mobility are the two principles used that are also common to all liquid crystalline phases. In lyotropic mesophases, solvent concentration and temperature may be used to facilitate order and mobility, whereas in thermotropic phases (amphiphilic molecules) the determinants are molecular structure per se and temperature. The structure of the amphiphile itself is also significant in lyotropic molecules.

The approach being developed at Mainz to exploit molecular order and mobility (based on inherent organization and reactivity within reacting species) tends to move away from the more traditional idea of synthesis using catalysts (heterogeneous or homogeneous), however effectively this has proved itself. According to Ringsdorf, living cells present us with a perfect example (a paradigm) for natural synthesis. We should attempt to emulate this

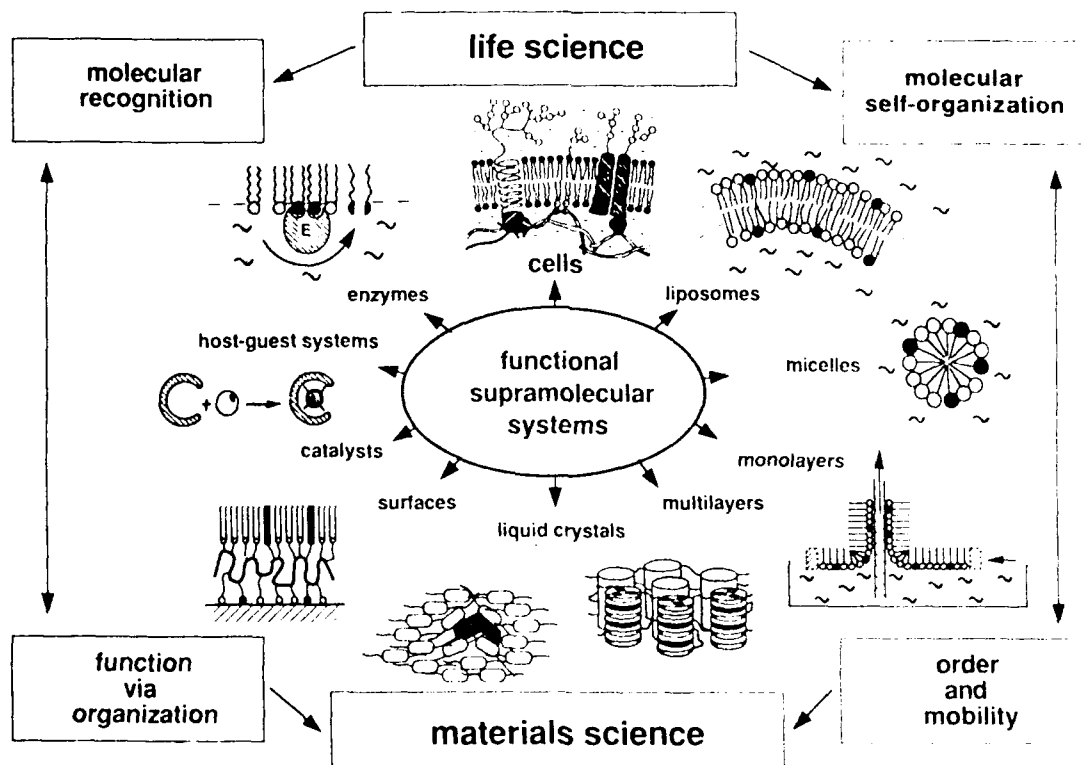


Fig. 1. Functional supramolecular systems—connecting link between life science and materials science.

in supramolecular synthesis in order to mimic nature, which is the ultimate objective of this methodology. So far, he has demonstrated that membrane-bound ligands can interact with receptor ligands organized as Langmuir-Blodgett (LB) films on surfaces. Reactions were carried out in ordered Langmuir-Blodgett films on liquid surfaces. This is an approach that is well developed at the University of Mainz.

Structural analysis has shown that protein may be attached to a lipid membrane through two biotin binding sites. This leaves two others free for further reaction and presents an opportunity for constructing useful protein-containing functional multilayers. In another example (which can be mentioned only briefly here), domains with regulated morphology may be created whenever phospholipase interacts with lecithin monolayers as a result of specific recognition that occurs between enzyme and substrate. This reaction is followed by an active phase of lipid cleavage that results in aggregation of the enzyme. Such processes are complex. However, they have been monitored by fluorescence labeling and fluorescent microscopy, since measurable quenching occurs whenever a reaction takes place (Fig. 2).

Professor J. Fraser Stoddart (University of Birmingham, U.K.) gave an interesting lecture on synthetic supramolecular polymers, which covered more than a decade of research. The overall thrust of the research here is also to mimic nature by means of a synthetic strategy. This strategy involves the highly ordered template-directed preparation of interlocked molecular systems, i.e., catenanes and rotaxanes, schematically shown in Fig. 3.

Despite the intense research into molecular assemblies, the results are still only oligomeric in construction, but they have been synthesized and characterized. Specifically, highly ordered polyrotaxane-like compounds and double helical "polymers" have been initiated. Basically, the self-assembly process is used. It depends on aromatic  $\pi$ - $\pi$  interactions that involve acyclic and cyclic molecules that contain  $\pi$ -electron-rich diphenol or dinaphthol moieties and  $\pi$ -electron-deficient bipyridium rings. It appears that supramolecular polymer systems may be synthesized with this methodology developed by Prof. Stoddart and coworkers.<sup>2</sup>

Dr. W. DeWinter (R&D laboratories, Agfa-Gevart, Belgium) described the tailoring of supermolecular polymer particles by using recognizable block copolymers of the poly (sulphonated glycidylmethacrylates), which are used as surfactants in the emulsion polymerization of vinyl- and acrylic-type monomers. The particles produced exist as structured "electrostatic" bilayers.

The synthesis of other supramolecular systems were described by Prof. Attilio Cesàri (University of Trieste, Italy). His presentation dealt with supramolecular structure in polysaccharides. Long-range structural order in solution and related rheological properties constituted the main focus of this talk.

Professor V.P. Zubov (Shemyakin Institute of Bioorganic Chemistry, Moscow) described the work of his group with functional mono- and multilayer polymeric films. Materials studied were based on lipid-like monomers with immobilized proteins, such as bacteriorhodopsin. Protein in copolymerized lipid-protein layers can be made with fixed conformations, the object being to design biosensors with photoelectrical, spectral, and/or enzymatic properties.

Professor Hiromi Kitano and coworkers (Kyoto University, Japan) used similar principles, based on mutual recognition between polymerized liposomes, as a model for cell membranes. For example, turbidimetry and fluorescence methods were used to demonstrate recognition and directed attack of the in-carrying (partly polymerized) liposome by a biotin- and phospholipase A<sub>2</sub>-carrying polymerized liposomes.

Supramolecular architectures based on mono- and bichain lipopeptides and liposaccharides macromonomers were discussed by Dr. B. Gallot and coworkers (CNRS, France). These monomers were polymerized with various acrylates and acrylamides to produce lamellar, cylindrical, and liposomic arrangements that are characterized by diffraction and microscopy; they are used to evaluate drug encapsulation and other biomedical applications.

Colloidal aggregates of small detergent and interacting polymers were investigated in relatively concentrated solutions by Prof. B. Chu (State University of New York) by using several scattering techniques. Information on particle size, size distribution, and aggregate conformation was obtained, particularly by synchrotron X-rays. Supramolecular organizations formed by using intermolecularly bonded polar statistical polymers were prepared and studied by Reimund Stadler et al. (University of Mainz). Thermoreversible complexes and entanglement networks were created through dipole-dipole interactions via polar functions on polybutadiene, polyisoprene, and other polymers. In "Self Organization of Hydrophobized Zwitterions," Dr. A. Laschewsky and coworkers (University of Mainz) synthesized and characterized several complexes for use in understanding their selective interactions with many inorganic salts and preparing homogeneous blends of salt and polymer.

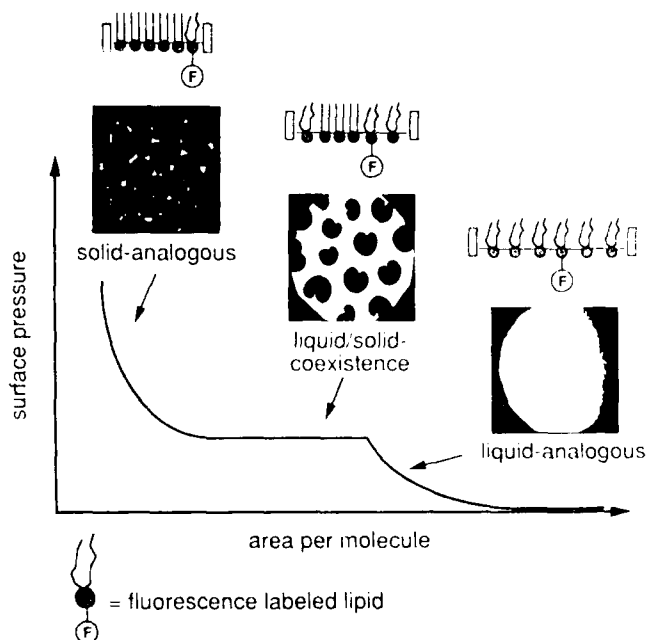


Fig. 2a. Phase behavior of a lipid monolayer doped with a fluorescence lipid: diagram and appearance under the fluorescence microscope: in the liquid-analogous phase, the fluorescence dye is homogeneously distributed in the monolayer; in the phase transition region there are solid-analogous lipid domains, which appear dark because the fluorescence dye is not incorporated, in a bright liquid-analogous matrix; the solid-analogous phase is almost completely dark.

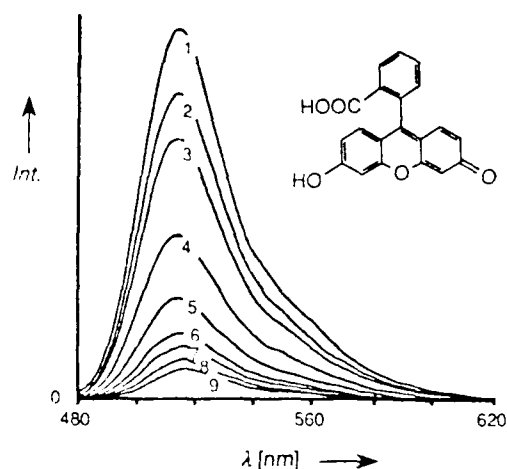


Fig. 2b. Fluorescence spectra of fluorescein ( $2.7 \times 10^{-12}$  M) before (1) and after (2-9) incubation with the anti-fluorescein antibody: increasing the antibody concentration increases the quenching of the fluorescein fluorescence; antibody concentrations: (2)  $8.5 \times 10^{-13}$  M; (3)  $1.7 \times 10^{-12}$  M; (4)  $3.4 \times 10^{-12}$  M; (5)  $5.1 \times 10^{-12}$  M; (6)  $6.8 \times 10^{-12}$  M; (7)  $8.5 \times 10^{-12}$  M; (8)  $1.1 \times 10^{-11}$  M; (9)  $1.5 \times 10^{-11}$  M.

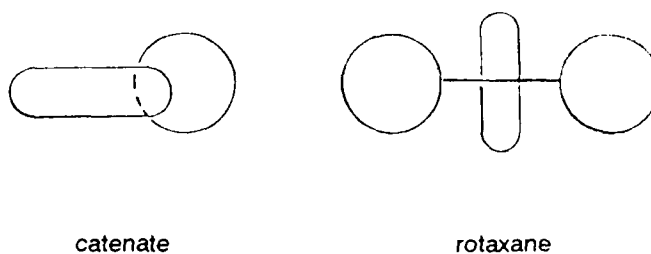


Fig. 3. Interlocked molecular systems

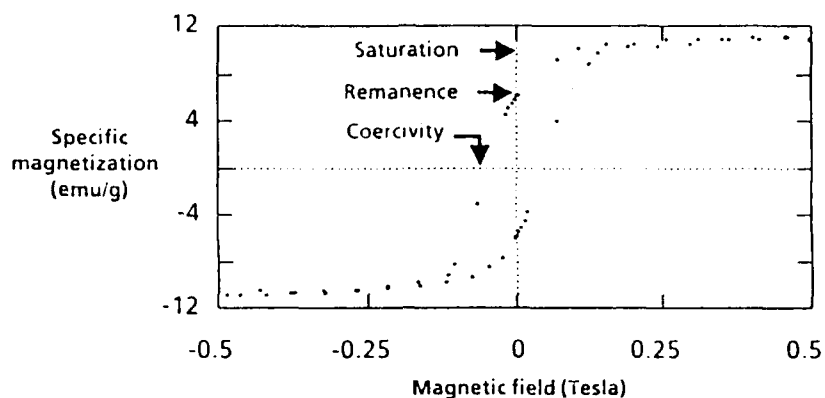


Fig. 4. Magnetic paper hysteresis loop (CTMP + 17.1%  $\gamma$ - $\text{Fe}_2\text{O}_3$ ).

## LIQUID CRYSTALLINE POLYMERS

Switching now to a different state or level of macromolecular organization, Dr. C. Noel of ESPCI/CNRS, Paris, presented an overview of self-organization in polymer mesophases. Professor A. Skulous (IPCMS/CNRS Strasbourg) described "Investigations of Ordered Supramolecular Architectures" in molecular and macromolecular materials. He outlined the basic morphologies of mesophases and described their characterization by using diffraction methods that indicate the shortcomings of optical techniques. These techniques provide only classical information about mesophases. The difficulty of characterizing flexible side chain polymers was also mentioned. Skulous stressed that the polymer chain backbone must fit the lattice, even if the side groups do not always do so. This is not always realized by some investigators.

Dr. Rudolf Zentel (formerly at the University of Mainz, but now at the University of Düsseldorf, Germany) lectured on the synthesis and molecular dynamics of functionalized LC polymers, some of which were cross-linked to give LC elastomers. Molecular structure was related to molecular properties and macroscopic properties.

Dr. Gerald Farrow (Hoechst Celanese Corporation, Charlotte, North Carolina) provided an interesting overview of commercial polyesters and their properties (Vectra and Vectran materials) and a comparison was made with Kevlar, for their longitudinal mechanical properties and as well as in various applications that are both environmentally and mechanically demanding.

Dr. N. Nakanishi, Institute for Polymers and Textiles, Tsukuba, Japan, discussed the "Synthesis of Novel Macromolecules Using Solid State Polymeriza-

tion of Diacetylenes" He listed some syntheses of diacetylenes that provided cross-linked crystals, starting from diamine or metal ion diacetylene dicarbonylic acids. Ladder polymer were made from two diacetylene moieties. Dipolyacetylenes were also synthesized where the two chains were  $\pi$ -conjugated to each other. Novel fused polymer rings with as many as  $10\pi$ -electron/repeating unit were made, providing a novel series of regular structured polymers.

## NLO AND LO POLYMERS

A very succinct and informative presentation was made by Professor David Bloor (Department of Physics, University of Durham). He dealt with the structure and properties of extended coiled and helical polydiacetylenes, pointing out that their conformation was responsible for the supramolecular structures produced and also their properties in practice. The dependence of structure on linear optical (LO) and nonlinear optical (NLO) properties was noted. Spectroscopic methods were mainly used for material characterization and stability testing was made under normal laboratory conditions. Several papers and posters described nonlinear optics research.

Many posters dealt with the preparation of supramolecular ionic clusters that result in complex structures, likewise thermotropic. Polymer mesophases received much space in this poster sessions. One of the more striking was a presentation by Prof. R.H. Marchessault<sup>3</sup> (McGill University, Montreal, Canada), "Magnetic Cellulose Fibers and Paper; Preparation Processing Magnetization Characteristics" (Fig. 4). [Reference 3 describes important uses for "lumen-loading" to produce specialty cellulose

fibers containing ferrite particles that have the potential for information storage, security printing, and other applications.]

Other lectures and posters were along similar lines; in particular an invited presentation by Drs. B. Keller and G. Wenz (Max Planck Inst. für Polymerforschung, Mainz) on "Inclusion of Polymers by Cyclodextrine in Aqueous Solution." In principle they demonstrated that cyclodextrin rings (CDXs) could actually be threaded onto a hydrophilic polymer chain; they characterized the product by viscometry, nuclear magnetic resonance spectroscopy, and microcalorimetry. Even "dethreading" was verified experimentally. Inclusion was found to occur relatively fast (minutes) for layer species such as heptakis-(2, 6-di-o-methyl)- $\beta$ -CDX, whereas several days were required for smaller host species like  $\alpha$ -CDX. [The chemicals and kinetic details are described in Ref. 4.]

## CONCLUSIONS

This meeting provided a perspective on potential approaches to linking natural and material science in a manner that would result in considerable pay-off in the future, particularly if the basics of molecular recognition and self-organization can be synergistically brought together. The organization of polymeric mesophases is a path en route to self-organization that provides a low free-energy path to morphologi-

cal texture building, provided adequate time is provided for the arrangement of molecules, even though many defects also exist. Colloidal systems are yet another type that fall into this supramolecular classification of materials. "Molecular Legos<sup>®</sup>," exploited through imaginative synthetic approaches closely related to nature, must lie ahead in materials synthesis.

## REFERENCES

1. Michael Ahlers et al., "Specific Interactions of Proteins with Functional Lipid Monolayers—Ways of Stimulating Biomembrane Processes," *Angew. Chem. Int. Ed. (English)* **29**, 1269-1285 (1990).
2. Peter R. Ashton et al., "A [2] Catenane Made to Order," *Angew. Chemie. Int. Ed. (English)* **28**(10), 1396-1399 (1989).
3. Serge Ricard and Robert H. Marchessault, "Preparation of In Situ Magnetically Loaded Cellulose Fiber Materials," *Materials Res. Soc. Symp. Proc.* **197**, 319 (1990).
4. J. James Sasaki et al., "Stability of 1:1 Complexes Between Aliphatic Alcohols and  $\beta$ -cyclodextrins in Aqueous Solution," *Fluid Phase Equilibria* **49**, 281-289 (1989).

# Time-Resolved Macromolecular Crystallography

by Joseph H. Magill

## INTRODUCTION

Synchrotron X-ray sources permit exposure times in the 500  $\mu$ s (for strongly scattering protein crystals) to 100 ps (for well-organized organic materials) range. However, developments in accessories (detectors, for example) have not kept pace with the growth in high-intensity radiation sources.

The "Time-Resolved Macromolecular Crystallography" meeting was sponsored by and held at the Royal Society, London, on 29 - 30 January 1992. It was attended by participants from nine different countries. Professor D.W.J. Cruickshank, FRS (University of Manchester Institute of Science and Tech-

nology) in opening the meeting, alluded to its timely nature now that strong X-ray sources have remarkably reduced the experimental time scale for recording diffraction data.

In biophysical chemical processes, other practical difficulties are encountered. One of these is initiating in situ kinetic changes in materials without producing intolerable loss of sample crystallinity. Records may be made of rotating crystals in several instances. In synthetic polymers that are less well structured than proteins, physical transformations (except for phase transformation per se) are more limited experimentally. Even so, progress has been made in the last few years. With current and

planned\* synchrotron sources, very-high-intensity monochromatic and polychromatic X rays can be produced. Professor Cruickshank provided a thumbnail sketch of the developments in crystallography from Laue (1912) until the present, when diffraction is well-established for investigating all kinds of materials.

## OVERVIEW

Rather than describing selected presentations, an overview is provided of the successes and difficulties of using strong X-ray sources for investigating macromolecular (natural/protein) materials. Synthetic polymers were not considered at this meeting although many of the research experiences encountered are equally applicable to these materials.

In investigating natural materials, the most significant problems encountered appear to be:

- deterioration of X-ray diffraction patterns arising from chemical and structural events. It was generally agreed that the problem was more serious for Laue diffraction since this technique needs a quality crystal. Sometimes cross-linking may be used to stabilize the crystal, but this may impair its diffracting ability.
- better software is required for data processing.
- weak Laue reflections were eliminated from data analysis by some investigators, but other crystallographers found that structure determination was improved when these were included (it was pointed that false features may be introduced if this type of information was neglected).
- enhanced experimental design was encouraged for better data collection (here, improved collectors are required).

In addition, it was suggested (and indeed demonstrated), that the lifetimes of diffracting species may be improved by using:

- properly selected cage compounds,
- temperature-jump experiments (T-jump)
- pressure-jump experiments (P-jump)

- procedures to prolong quality diffraction lifetimes compared to the actual data collection time. Here the more powerful synchrotrons (under construction) should improve the situation.

Again, experimental advantages may be brought about by enhancing crystal diffracting times through

- changing pH,
- using retarding substrates or "slow" enzymes,
- using mutants, but being cognizant that the transformation mechanism may be dependent on them,
- using solvents and/or cooling may be advantageous, but recognizing that other problems may be introduced.

Kinetics experiments using spectroscopic methods ought to be used even though these are less definitive morphologically than X-ray procedures. Better still, both approaches should be used to complement each other. The actual specimen temperature (in the beam) must be monitored carefully and continuously because it can increase by as much as 15°C during X-ray measurements. Changes of this magnitude can adversely affect results, especially if the specimen is sensitive to trapping or absorption of enzymes in some temperatures regimes (near transitions).

Radiation damage is regarded as a secondary process, but it can be diminished in some ways, e.g. by low temperature and choice of wavelength. Chemical protection against x-radiation synchronicity in experimentation (exposure and data collection) is often a challenge that is difficult to overcome.

In addition to Laue and monochromatic experimentation procedures, more Weissenburg facilities were encouraged for data recording to facilitate crystal structure determinations. The most sophisticated facility of this kind is the Japanese Photon Library. Apart from its uniqueness, it is far removed from the West and travel to it is expensive. For this reason, it was suggested that some thought be given to building instruments of this type in the West. With such equipment, few X-ray exposures would be required and damage to crystals would be minimized.

A knowledge of chemistry is needed when conducting time-resolved studies with macromolecules. Kinetic back-up and other spectroscopic techniques ought to be included. In view of the experimental difficulties usually encountered in crystallography of

\*Next-generation synchrotrons at ESRF, Grenoble, and ELECTRA, Trieste, will soon be completed.

this kind, some investigators advised that kinetic studies should be devoted to slow kinetics until stronger radiation sources become available.

An alternative approach is to use the computer simulation of  $SN_2$  type reactions that is now receiving some attention. The total energy,  $E_{\text{total}}$  of biopolymers can be computed using the relationship

$$E_{\text{total}} = E_{\text{bonds}} + E_{\text{angles}} + E_{\text{torsion}} + E_{\text{non-bonded}} + E_{\text{coulombic}} + E_{\text{quantum}}$$

The last term is semiempirical and relates to those atoms actually involved in bond-breaking and bond-making. Such modelling and reaction simulation has been carried out recently for simulating chemical reaction involving triphosphate isomerase, histidine 95, and other amenable species. This approach, although complicated, may provide insight into kinetic processes (that may be compared with experiment). The approach has considerable flexibility, since a particular transformation can be interrogated at any time during the simulated reaction of these complicated molecules. Stabilization energies can also be computed and compared with experiment to serve as guidelines.

The conference was summed up nicely by Professor G.A. Petsko (Brandeis University) who pointed up past, current, and future problems in time-resolved enzyme crystallography. He stressed the need for computational analysis; it can serve as a useful guide and holds much promise for the future when higher energy X-ray sources, improved data collection, storage, and processing procedures become available.

Sir David Phillips (Advisory Board for the Research Councils, London) chaired the panel discussion; panel members were Professors G.A. Petsko (Brandeis University), K. Moffat (University Chicago), and Louise N. Johnson (University Oxford).

In opening the discussion, Phillips said that this conference was a watershed in structural biology. Although kinetic crystallography was conducted on muscle a long time ago, there was now a new start

(beginning) in this area since the technical problems are better defined. The objective now focuses on addressing specific biochemical problems, and the Laue method is now being used to solve them. In essence the polarized nature of synchrotron radiation was pointed out. It was stressed that its significance in regard to the flexibility of macromolecules should not be ignored.

Optical probes were discussed further, and fluorescence spectroscopy was suggested as a significant investigative tool. Other optical probes were also encouraged. It was stressed, too, that a good crystal may be destroyed in 100 ps! The influence of low-resolution reflections on X-ray diffraction maps were worthy of closer investigation. For P-jump investigations, hydrostatic rather than gas pressure applications at short wavelengths were discussed.

The pros and cons of wavelength range/interval were debated, but a range preference was not resolved. Among other things, mention was made that the low-temperature methods, which were frequently used 20 years ago, were being used less, and low-temperature measurements could be used to trap intermediates. Cooling and subsequent sample warming techniques have proven to be advantageous sometimes.

It was also stressed that caution must be used to maintain chemical reactivity when the Arrhenius relationship is truly valid. These comments provoked debate over some difficulties where valued judgments were commonly used in crystallographic studies. For instance, the merits of the strict use of relatively low R values as a definitive criterion for good results were debated. Although this conference was primarily focused for the protein crystallographer, there were gems of interest to the material crystal structure investigator. For instance what is known of artifacts induced in synthetic polymers by synchrotron radiation?

Although this conference has limited documentation except from abstracts, it will be reported on in future conference proceedings of the Royal Society.

# Microbiology

## A Treasure Chest of Expertise — The Centre for Applied Microbiology and Research

*by Lieutenant (junior grade) Malcolm B. Johns, Office of Naval Research, European Office. Lt(j.g.) Johns is assigned to the Chemical and Biological Defense Establishment at Porton Down performing validation studies on polymerase chain reaction identification of biological threat agents.*

### INTRODUCTION

For the Navy researcher who needs category III or IV pathogens but does not have the facilities to produce them, I have identified a resource able to resolve the problem. The Centre for Applied Microbiology and Research (CAMR), Porton Down, U.K., has a varied concentration of facilities and technical expertise, with several active research programs in diagnostics, therapeutics, and production methods. Established in 1979 when the Public Health Laboratory Service (PHLS) took over responsibility for what was then the Microbiological Research Establishment, CAMR has become a unique entity in PHLS in that it must justify its existence by the revenue it generates. CAMR offers highly specialized services to academia, industry, health care, and military organizations. The mission of CAMR is to assist these groups in the commercial exploitation of products and processes that result from applied research programs.

### ORGANIZATIONAL STRUCTURE

CAMR is organized into four divisions, the Division of Biologics, the Division of Biotechnology, the Division of Pathology, and the Central Division. Points of contact are located in the Appendix.

### DIVISION OF BIOLOGICS

My tour of the Division of Biologics was conducted by Dr. Peter Turnbull. After meeting with him, Dr. H. Trantor, and Dr. Peter Hambleton (head of the division), I was duly impressed by the capability of this division. The focus here is the exploitation of pathogenic organisms for therapeutics and diagnostics. The Division of Biologics is divided into six working groups: Animal Cell Technology, Molecular

Virology, the European Collection of Animal Cell Cultures (ECAC) Toxinology, Bacterial Antigens, and Production. The Animal Cell Technology Group is involved in the development and scaling up of processes involving animal cells, including vaccines, monoclonal antibodies, and therapeutic proteins. The Molecular Virology Group conducts research on the application of Molecular Genetics techniques to the development of new products for the prevention and diagnosis of viral diseases. Specific areas of research include the development of a new measles vaccine and studies on tick-borne encephalitis viruses, including Russian Spring Summer Encephalitis.

The division houses the European Collection of Animal Cell Cultures, a repository for patented cell lines. The ECAC also characterizes cell lines and is capable of removing contaminating cell types and mycoplasmas. The Toxinology Group focuses on the study of bacterial toxins for better understanding of the biochemical mode of action, and on the development of vaccines, therapeutics, and rapid diagnostics. Specific areas include Botulinum toxin and staphylococcal toxins.

The Anthrax Reference facility for this group, headed by Dr. Peter Turnbull, offers detection of the anthrax organism for public health and industry. The Bacterial Antigens group is currently developing an safer and more effective than the current whole-cell vaccine. In addition, the group is studying the pathogenesis of meningococcal disease.

The Production Group is responsible for the pharmaceutical manufacturing of biological products and the high containment facilities required for the production of pathogenic organisms. The main product produced is Dysport, a highly purified Botulinum toxin preparation that is used in the treatment of spastic disease. Other products include Kveim antigen for the diagnosis of patients suffering from

sarcoiditis, Pertussis vaccine, *Pseudomonas* vaccine, *Clostridium perfringens* enterotoxins, and animal cell cultures.

Dr. Trantor is in charge of small-scale production of ACDP\* category III pathogens and/or toxins. In addition, expert assistance is offered involving the scaling up of fermentation systems from small, bench-top level to the 25 to 50 liter scale. Dr. Trantor indicated that once optimized conditions for this scale have been obtained, his group can then assist in further scaling up to the 150 liter scale, with downstream processing available. His attitude is "we will grow just about anything anybody wants."

The Biosafety Unit is available on contract for design and validation of containment equipment. It offers a consultancy in Europe for the evaluating facilities and equipment for compliance with containment regulations.

## DIVISION OF BIOTECHNOLOGY

This division focuses on the production of microbial proteins for therapeutic and diagnostic use. It does this by bringing together biological, genetic, and biochemical research with applied engineering and computerized process skills. The division is divided into six working groups comprised of: Molecular Genetics, Microbiology and Fermentation, Development and Production, Protein Biochemistry, Diagnostic Enzymology, and Sensor Development.

The Molecular Genetics Group task is the cloning, sequencing, and expression of bacterial and mammalian genes that encode for therapeutic and diagnostic proteins. The group is also developing "cassette vectors" that will allow rapid assembly of cloned genes and regulatory regions that facilitate high level expression for production purposes. A DNA probe program is in place for the rapid identification of pathogenic bacteria. The Microbiology and Fermentation group maintains a bacterial culture collection and supplies seed cultures for research and production. Two major research areas are the biodegradation of pollutants, such as polychlorinated biphenyls, and genetic characterization of thermophilic bacteria which involve the development of cloning systems for the production of thermostable proteins.

The Development and Production Group works on pilot-scale fermentation and extraction of proteins having therapeutic or diagnostic use for research, clinical trials, or direct sales. Products produced are the world supply of asparaginase, which is the use in

the treatment of acute lymphatic leukemia, recombinant human growth hormone (by license for UK supply only), and microbial cultures for world-wide distribution. The group also has expertise in the design and development of computerized production facilities.

The Protein Biochemistry group is responsible for developing and producing specialized proteins for clinical use. Examples include tissue plasminogen activator, human pituitary hormones, and antibody/enzyme conjugates for tumor therapy. Research efforts attempt to engineer proteins by altering immunogenic, kinetic, and other properties to improve the therapeutic or diagnostic usefulness. To support this effort, the group uses three-dimensional computer modeling on a microvax computer. Research on novel separation methods is another major area of research by the group.

The Sensor Development Group is concerned with the development of sensors for measuring biomass, ions, and organic species for clinical and bioprocess use. Research is on the use of lasers for detecting viral and bacterial particles and for measuring protein interactions and structure.

## Division of Pathology

This division is divided into four groups: The AIDS and Special Pathogens Group, the Diagnostics Group, the Bacterial Metabolism Group, and the Pathogenesis Group. The AIDS and Special Pathogens Group is currently testing vaccine strategies for HIV by using the SIV model in rhesus monkeys. The group also does research on improved methods of detecting Ebola, Marburg, and Arena viruses.

I met Dr. G. Lloyd from the Diagnostics Group. This group is a World Health Organization Reference Center for viral and bacterial pathogens. The diagnostic capability is extensive. For viral pathogens, they are capable of detecting Lassa, Marburg, and Ebola fevers. Other agents include the alpha viruses, flaviviruses, arboviruses, plus several other exotic types. The group also diagnoses infections with Rickettsia, Coxiella, Borrelia, and a range of exotic bacteria. Research on Q-fever is being conducted by Dr. D. Rutter within this group as well.

The facilities include a large category IV suite, with a unique feature of incubators, refrigerators, and centrifuges built into the floors of the cabinets. This allows sample processing without removal from containment while maximizing space within the cabinet.

The Bacterial Metabolism Group studies the role of normal flora in chronic and latent diseases.

\*Advisory Committee on Dangerous Pathogens

The Bacteria and Cancer Section is concerned with the role that human intestinal flora play in the initiation and promotion of colon and gastrointestinal cancer. Research on Campylobacter infection is being performed by the Intestinal Flora Section to better understand the pathogenesis of the organisms and to develop diagnostic kits.

The Pathogenesis Group studies infection by HIV, Bordetella pertussis, and Legionella pneumophila. A major area of research and expertise is in aerosolization as a route of transmission of disease. The effects of droplet size, humidity, etc., are being studied to help identify the infective nature of aerosols.

## CENTRAL DIVISION

The Central Division is the service group for CAMR. The division is responsible for the administration, finance, quality assurance of products, occupational health, safety, media, and glass preparation, and engineering aspects of the center. By having this division, CAMR minimizes down-time; trained personnel are on site to repair equipment when a fault occurs. In addition, the Quality Assurance Group is responsible for the quality of manufactured products.

## FACILITIES

CAMR is located in a large building which, although not modern, is capable of supporting the Center's efforts; it can be easily modified to meet changing regulations. The Center has a large animal facility, capable of handling animals ranging in size from mice to pigs. One section is reserved for an internal breeding program for mice and rabbits, maintaining a virus-free environment. The "toxic wing" is used for active research, with around 15 rooms capable of category III containment in place.

A current renovation program will upgrade several rooms for category IV containment. Several

fermentation units are available, ranging in size from 1 liter up to 150 liter capacity. Each unit is located within its own category III cabinet. This allows dangerous pathogens and toxins to be produced. The laboratories are set up as category III sites, with glove boxes for work with pathogens. As mentioned before, an entire suite is dedicated for category IV pathogens. My impression is that the center is well-equipped despite the budget constraints imposed by the British government.

Pharmaceuticals are produced in a separate building, which has been designed to meet the rigid requirements for this type of work. Of particular interest is that the staff has experience with U.S. Food and Drug Administration regulations concerning the manufacture of injectable pharmaceutical components and vaccines.

## SUMMARY

I found the staff of CAMR to be easily approachable, with a "can do" attitude. Their extensive experience in diagnosis of infectious disease coupled with sophisticated research facilities provides opportunities for useful collaboration with the Naval research community. CAMR is willing to consider performing contract research and is currently performing a vaccine development project for the United States Army Medical Research Institute of Infectious Disease. The facility is a body corporate under British Law and is authorized to enter contractual agreements. It is of interest that CAMR is required to justify its existence in part by the revenue generated from pharmaceutical and diagnostic sales and by contractual work. I am currently working with CAMR to perform animal experiments required for the rapid identification project, and they have been most helpful in assisting me in the experimental design. With limited category III and IV facilities available to the Naval research scientist, CAMR should prove to be a valuable resource for research on infectious disease.

## APPENDIX

### Points of Contact\*

CAMR is located at Porton Down near Salisbury. The facility maintains close ties with the Chemical and Biological Defense Establishment, which is located on the same site. The address is

\*CAMR is currently being restructured, and group heads may change as a result.

PHLS Centre for Applied Microbiology and Research, Porton Down, Salisbury, Wiltshire SP4 0JG, United Kingdom. Telephone from the United States 011-44-980-610391. My point of contact was Dr. Peter Turnbull who is with the Division of Biologics. Following is a list of the division and group heads.

Director of CAMR Porton: Professor Jack Melling

Division of Biologics

Head: Peter Hambleton

Animal Cell Technology Group

Head: Professor Bryan Griffiths

Molecular Virology Group

Head: Dr. John Stephenson

The European Collection of  
Animal Cell Cultures

Head: Dr. Alan Doyle

Toxinology Group

Head: Prof. Jack Melling

Production Group

Head: Dr. Peter Hambleton

Bacterial Antigens Group

Head: Dr. Andrew Robinson

Division of Biotechnology

Head: Professor Tony Atkinson

Molecular Genetics Group

Head: Dr. Nigel Minton

Microbiology and Fermentation Group

Head: Dr. Richard Sharp

Development and Production Group

Head: Dr. Roger Sherwood

Protein Biochemistry Group

Head: Dr. Mike Scawen

Diagnostic Enzymology Group

Head: Dr. Peter Hammond

Sensor Development Group

Head: Dr. David Clark

Division of Pathology

Head: Dr. Peter Greenaway

Aids and Special Pathogens Group

Head: Dr. John Oram

Diagnostics Group

Head: Dr. Peter Greenaway

Bacterial Metabolism Group

Head: Dr. Michael Thompson

Pathogenesis Group

Head: Dr. Edward Ashworth.

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## Oceanography

### Meteorological Research at the British Antarctic Survey

*by J.P. Dugan. Dr. Dugan is an oceanographer currently serving as a Liaison Scientist for Physical Oceanography in Europe and the Middle East for the Office of Naval Research European Office. Previously he formed and directed the Field Measurements Department for Arete Associates. Earlier, he was at the Naval Research Laboratory, Washington, D.C.*

#### INTRODUCTION

The Antarctic you say? Why would the Office of Naval Research (ONR) or the ONR European Office care about the Antarctic? The Navy doesn't

operate there—why should we care about research in the Antarctic? Actually, the U.S. Navy does operate in the Antarctic. The U.S. research bases in the Antarctic are supported by VXI-6, which operates out of Christchurch, New Zealand, with five

cold-region-capable LC-130s. These aircraft and several helicopters spend the warmer months of the year operating in Antarctica under the auspices of the Division of Polar Programs of the National Science Foundation.

They fly all around the Antarctic continent, supporting science and providing logistical support for the bases. They recently completed almost 25,000 flight hours in four years without a major mishap. The weather forecasts for these operations, in particular, are supported by U.S. Navy forecasters at McMurdo Base and at the Naval Support Force Antarctica in Port Hueneme, California. Because the weather in Antarctica can be severe and variable, providing the best possible weather forecasting is critical.

In a wider sense, though, research on all physical processes (including the weather) in the polar regions is important. The Navy has vital interests in more indirect applications in a number of sciences. The research at the British Antarctic Survey (BAS), in particular, has a number of individual programs that are of interest to the U.S. Navy. The work in the Marine Life Sciences Division was visited recently by Dr. Keith Cooksey of this office.<sup>1</sup> This present report provides information obtained during visits to the Ice and Climate Division and, particularly, to the meteorology research sections in this division.

## BACKGROUND ON THE INSTITUTE

Exploration of the polar regions has been a special interest for the British since the Antarctic was first visited by Captain James Cook in 1772. This was followed by numerous explorers and scientists, and the efforts have resulted in many discoveries of both geographical and scientific interest in the polar regions. With respect to the southern ocean, the Falkland Islands Dependencies Survey was absorbed by the BAS in 1967 when it became a Natural Environment Research Council (NERC) Institute.

The BAS is the primary United Kingdom scientific research institute devoted to the study of the southern polar region. It first occupied its present facility on the outskirts of Cambridge in July 1989, having moved from its older quarters in town where it had been located since 1975. It already is stretching the limits of its new quarters. BAS is presently funded by NERC at about \$50M per year; about half

of this is for capital improvements at both Cambridge and the Antarctic bases.

## ORGANIZATION

The current director is Dr. David Drewry who formerly directed the Scott Polar Research Institute (SPRI), which also is in Cambridge. The BAS has a total of 425 personnel; about 160 are permanent and 55 are temporary staff, about 70 are ship's complement, and 150 are contract staff. These personnel are organized into divisions, science themes, and major programs (Fig. 1).

The meteorology research groups in the Ice and Climate Division provide most of our direct interest in this report. The meteorology groups support the theme of pattern and change in the physical environment of Antarctica. Very large and active groups, however, are interested in the southern ocean and Antarctic terrestrial ecosystems and in ice and atmospheric chemistry. The discovery of the "ozone hole" by the chemistry group is the widest known work by any group at BAS in recent years. Before reviewing the meteorological research, it is worthwhile to review the publications of the organization and to provide some general information on the British stations in the Antarctic.

## PUBLICATIONS

The *BAS Bulletin* was a well-known house publication that had been produced since 1963, but it recently stopped publication. It has been replaced by the journal *Antarctic Science*, a newer and glossier publication by Blackwell Scientific for which BAS provides partial direct support. The objective of this new journal is to provide a forum for interdisciplinary interests in Antarctic studies. The editor-in-chief and two senior editors are BAS employees, and an additional 19 international members comprise the editorial board. *Antarctic Science* publishes articles in areas of both broad interest and in quite narrow scientific specialties in the polar sciences.

## RESEARCH STATIONS

Five permanent research stations are presently manned by the British:

- Bird Island, on South Georgia,
- Signy, on the South Orkney Islands,

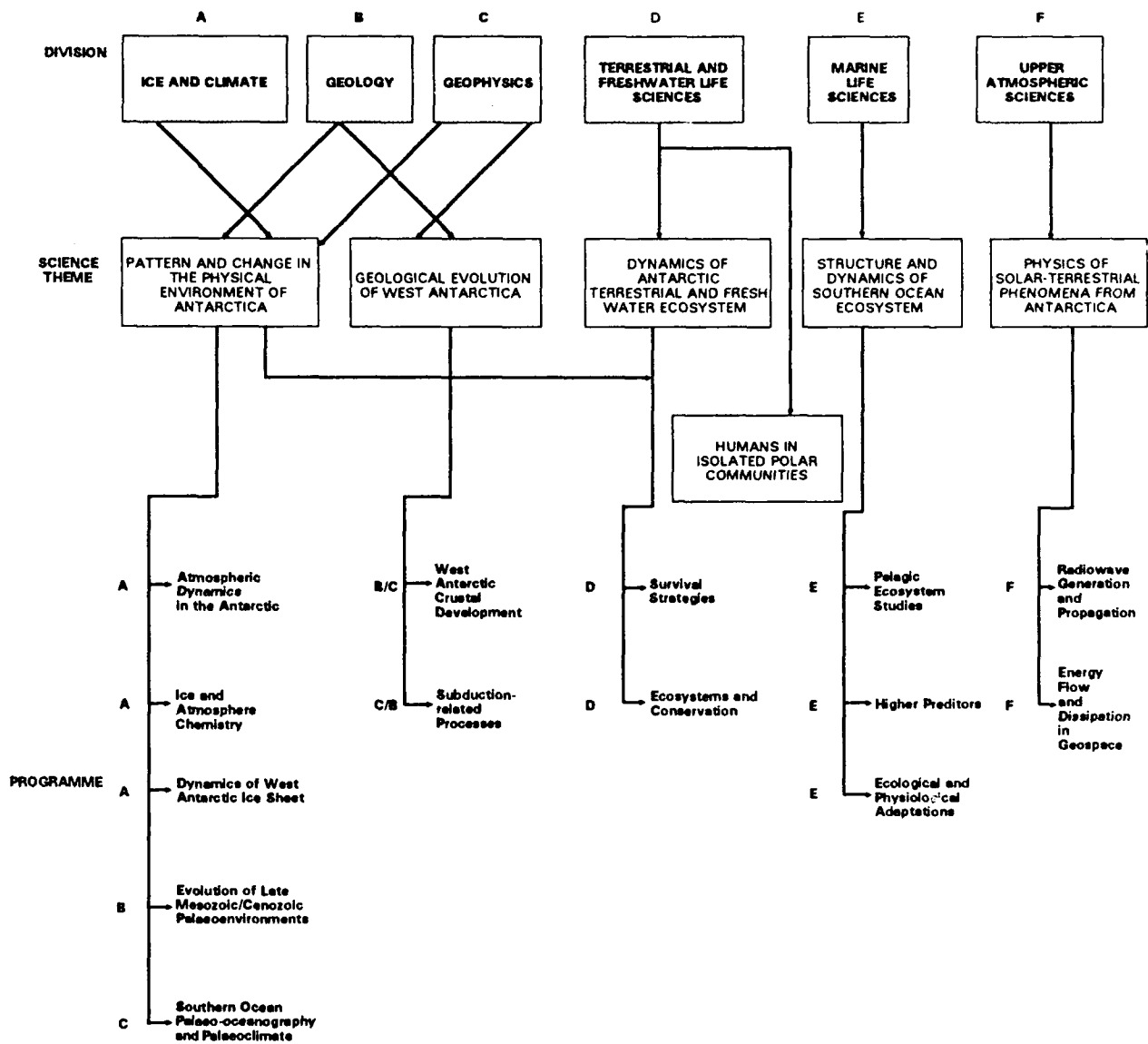


Fig. 1. Organization of BAS research divisions

- Faraday and Rothera, on the Antarctic Peninsula, and
- Halley, on the Ross Ice Shelf in the Eastern Weddell Sea.

In addition, a number of temporary bases are used for research and for air and/or land transit logistics during the austral summer, including:

- Damoy, out on the Peninsula,
- Rothera Point, midway along the Peninsula, and
- Fossil Bluff, farther in on the Peninsula.

The latter has several personnel during the summer only to provide weather service and aircraft support.

Ships are a major component of resupply, logistics, and scientific research in the Antarctic. The BAS uses the RRS *John Biscoe* and RRS *Bransfield* for resupply and logistics; it occasionally uses RRS *Charles Darwin* for research surveys and investigations. A new vessel, the RRS *James Clark Ross*, was delivered in June 1991. It has extra large laboratory spaces and workshops to support a wide variety of marine science programs for the BAS and the wider NERC marine science community.

Aircraft also are important tools, and the BAS has four Twin Otters for logistical support of equipment and personnel for field parties, aerial photography, and other duties such as dropping drifting buoys. The aircraft are used only in daylight during the busy austral summer months.

## ACTIVITIES IN THE ICE AND CLIMATE DIVISION

The Ice and Climate Division, headed by Dr. Elizabeth Morris, is organized by projects. The two sections reviewed in detail here are the In Situ Meteorology and Satellite Meteorology research sections.

### In Situ Meteorology

The Meteorology Section for nonsatellite applications is headed by Dr. John King. This section runs the meteorology programs at the Antarctic stations with six people in the field, about three in various stages of preparation or rotation, and six performing R&D in the laboratory. The observational program consists of surface observations at all four British stations, upper air observations at Halley Station, and data recording from the Modular Auto-

mated Weather Stations scattered about the continent.

The research is split into three general areas; the first is climatology. To support this, an historical database has recently been completed to study inter-annual variations on the Peninsula. As part of this work, data have also been acquired from weather buoys in Weddell Sea ice with David Crane of SPRI.

In total, about 14 upper air and 30 automated surface stations are on the continent, and much of the data is incorporated in the data set.

The purpose of this work is to understand the relationship of the ice sheet growth/decay with climatology, including effects of changes in precipitation, evaporation, and atmospheric transport of water vapor. The transport is especially important because of the relative scarcity of water vapor in the interior of the continent. Any changes in the climate are likely to change wind patterns that control the availability of water vapor for snowfall that builds the ice cap.

The climate consists largely of strong meridional winds around the continent, with synoptic weather systems traveling more or less around the periphery, but not penetrating far into the interior. Thus, there is minimal transport of water vapor from the ocean into the interior, and significantly less snow with increasing distance from the sea.

A strong area of research in this group is boundary layer studies at Halley Station. Halley is in the eastern Weddell Sea on a broad, flat ice shelf with very long, uniform fetch in the direction of prevailing winds. It is a convenient location to study boundary layer processes under stable atmospheric conditions. These conditions occur because of the relatively high amount of radiation cooling from the ice surface, occasionally causing thermal gradients of 1 degree Celsius per meter.

An experiment for these conditions is very difficult to set up over land. The high stability permits topographic steering and "blockage" of the boundary layer, with the result that measurements often are not representative of a wider area. The conditions at Halley make this location ideal. Strong stable conditions often occur over Arctic sea ice as well, and it is of interest to U.S. Navy scientists because of a need for improvements in boundary layer prediction models.

A recent major research effort on boundary layer dynamics was carried out as part of project STABLE (for Stable Antarctic Boundary Layer Experiment). A number of observational techniques were used to study the structure and evolution of the boundary layer. The instrumentation included three

Kaijo Denki sonic anemometers and a number of cup anemometers on a 30-m mast and two nearby 8-m masts, a Sensitron (2.3 kHz) monostatic sodar and, later, a 6-element microbarograph array. For the thermal balance, the system included platinum resistance thermometers for air and snow temperature profiles and a radiometer.

These surface observations were supplemented by radiosonde profiles, with the wind being obtained by using Omega receivers. The two types of anemometers were subjected to a thorough intercomparison test. The cup anemometers were found to have bias errors resulting from the formation of rime ice, in addition to the well-known problem of overspeeding in turbulent flow. The pressure sensors of the microbarograph array were buried in the snow to low pass the fluctuations resulting from small-scale turbulence in the surface layer (just as sea-bottom seismometers are buried in bore holes to reduce the effects of bottom boundary layer turbulence).

Observations made during and after STABLE have provided other results of further interest to us. The first is an observation that internal gravity waves in the lower troposphere are caused by layers of dynamic instability in the otherwise statically stable density profiles that occur. The observations of these waves were made in conjunction with researchers from the Universities of Leeds (S.D. Mobbs, theory) and Sheffield (J.M. Rees, pressure array). The pressure array data for specific wave groups of interest were space-time processed to calculate the dominant frequency and wavenumber of the group and, more generally, to estimate the dispersion relation.

These results can then be compared with theoretical calculations of the dispersion relation and modal shapes for trapped and unstable modes in the troposphere. The observed waves are theorized to be generated by instability in an elevated layer of low Richardson number that leads to dynamic instability; they are detected at the surface as they propagate away. In addition, wave groups have been seen propagating horizontally, trapped in the very stable layer near the surface. These waves probably were forced by topography.

The structure of turbulence in the stable layer near the surface also was studied. Even though the surface inversion that results from the strong thermal stability is largely destroyed during periods of high wind speed, the wind profile continues to exhibit significant deviation from the logarithmic form, and surface layer similarity theory does not provide a good description of the velocity and temperature profiles. The snow is not especially rough; estimates of the roughness using the stress and the logarithmic

form are less than 0.1 mm, even though sastrugi (wind-carved features in the snow of about 10 cm height) is omnipresent.

Measurements of the ratio of kinetic energy to mean stress and of temperature variance to heat flux show surprisingly little variation with either height above the surface or with the stability of the layer. This suggests that internal gravity waves continue to be important in the dynamics of the boundary layer. High winds were excluded from the data set, and there continues to be a lack of good data anywhere in polar regions during periods of extreme wind. This remains an area of interest.

Considerable collaborative work has been pursued with the Scott Polar Research Institute (SPRI), also in Cambridge.<sup>2</sup> An example of this collaborative effort is a study of pack ice motion in the Weddell Sea and its relation to weather systems. This is important because the sea ice conditions affect synoptic weather systems in complicated ways, and satellite retrievals of atmospheric conditions over the ice are fairly sparse. In turn, the wind stress from the atmosphere is a primary driver of the motion of the ice. As the ice is transported out of the Weddell Sea gyre, new ice is formed in coastal polynyas.

Two questions are: how fast is it formed, and how fast does it move through the system. The study was pursued by deploying and tracking an ice-hardened weather buoy and other drifting buoys, and comparing their drift motion with ship drift stations and weather analyses. The deployment of the buoy was part of the Winter Weddell Sea Project. Not surprisingly, it was found that the major fluctuations in ice drift are a result of the movement of the weather systems through the wind stress on the ice. As a result, an ice budget has been derived that is a balance of the change in ice area due to inflow from the study boundary and local ice formation.

### Satellite Meteorology

This group, headed by John Turner, applies data from polar-orbiting satellites to weather and climate processes in the polar regions. The major effort is developing techniques for maximum utility of the data. This is important because the remoteness and extreme conditions on the continent severely limit the availability of synoptic (that is, "weather") data. The in situ data from the manned and unmanned stations, including radiosondes, are important for weather analyses and predictions. To date, however, remote thermal imaging data from the NOAA polar orbiters have provided the bulk of the spatial input. This input is especially important for initial detection

of developing weather systems. The research is intended to improve this situation by using advanced instrumentation that is currently on or planned for future polar orbiters.

The TIROS Operational Vertical Sounder (TOVS) on the NOAA series of satellites provides vertical profiles of temperature and humidity, but this information is not accurate over the cold continent and sea ice. The work in the Satellite Meteorology group is intended to improve these retrievals. The idea is to use a library of radiosonde profiles compiled from the land stations and research vessels to select the best possible first-guess profile for a regression technique (first used by University of Wisconsin) for each satellite individual sounding. The compilation of profiles is in progress, and a collaboration with the European Centre for Medium Range Weather Forecasting (Reading, U.K.) has been established to provide numerical model fields for the first-guess profiles.

Two efforts in this group are associated with clouds. First, the detection of contamination of the TOVS data by the presence of clouds is troublesome, especially over the continent, and a compensation algorithm using a comparison of infrared and microwave data is under development. Second, algorithms are being developed for estimating upper air winds by "cloud tracking," which uses sequences of images from the Advanced Very High Resolution Radiometer channels. The general idea is not new. However, the implementation has been troublesome because of the development and decay of cloud elements and the ambiguity of cross correlation in the case of broken stratocumulus. An operator-intensive algorithm now is available and is used in meteorological investigations.

An example in point is a continuing program of case studies of important events in which the thermal, motion, and moisture fields provide a major input. This effort has improved the understanding of small-scale vigorous weather systems. John Turner has had a long-standing interest in the development

of subsynoptic vortices in both the Arctic and Antarctic; he is the secretary of the Polar Lows Working Group of the European Geophysical Society. This group includes satellite specialists like himself, forecasters, dynamic and physical meteorologists, and modelers. A workshop of this group on the subject of polar lows, with emphasis on new satellite techniques, is being supported by the ONR European Office in Iceland in June of this year.

## ICE MECHANICS

There has been significant research on ice mechanics at BAS in the past, but it has primarily been concerned with glaciology (the study of the great ice masses), and this has been focused mostly on the dynamics of the ice sheet over the continent. Only recently has interest been expressed in the dynamics of sea ice. There now is an emerging program on the interactions at the edge of the floating glaciers, and out-into-the-sea ice. This is a NERC Community Research Program in which BAS will be the lead institution.

BAS has advertised an RFP that is soliciting proposals from university groups and is intended to support a coalition between BAS and those groups. Objectives include modeling the growth, movement, and decay of the seasonal sea ice surrounding the continent and ice shelves. It is expected to be a three-year program, and there are appropriate direct linkages with similar work in the U.S. This is an opportunity for cooperative work that should be pursued.

## REFERENCES

1. K.E. Cooksey, "The British Antarctic Survey, Cambridge," *ESNIB* 91-05, 21, Sept. 1991.
2. J.P. Dugan, "Scott Polar Research Institute at Cambridge University," *ESNIB* 91-06, 31-34, Jan. 1992.

# Wave-Ice Interaction Workshop at Scott Polar Research Institute, Cambridge

by J.P. Dugan.

## INTRODUCTION

Theories and observations of waves in sea ice were discussed at a small workshop organized and conducted by Dr. Peter Wadhams, director of the Scott Polar Research Institute (SPRI), Cambridge, United Kingdom, and Dr. Vernon Squire of the University of Otago, Dunedin, New Zealand. Sponsored by the International Association for the Physical Sciences of the Ocean, the workshop was held at SPRI on 16-18 December 1991. Major subtopics discussed included waves near the ice edge, waves in continuous ice cover, ambient noise, and remote sensing techniques.

Most attendees gave an invited lecture on one or more topics in their specific expertise. Dr. Wadhams has a collection of all overhead transparencies that were shown. The results and recommendations of the workshop are expected to be published as a workshop report in an issue of *EOS, Transactions American Geophysical Union*.

The interaction between ocean waves and sea ice is important for several reasons. Near the ice edge, ocean surface waves are a dominant process associated with freeze up, melting, and acoustic noise generation. In the interior, several different types of waves are observed.<sup>1</sup> These are important because they are elements of the multivariate problem of sea ice dynamics. The waves are also useful as diagnostics of the physical processes that are occurring.

In the marginal ice zone, discussions primarily were about predictions and measurements of ocean surface waves interacting with a solid ice floe of semi-infinite extent or one or two isolated floes. These situations are mathematical idealizations that have only recently been solved with reasonable accuracy. Special attention was given to the threshold stress for floe breakage, which is caused by the incident wave field.

Generalizations of the model to multiple floes that are closely spaced have not been formulated. This multiple scattering problem is an interesting one, and it was discussed in some detail. Although

not the subject of specific presentations, other topics included generation and maintenance of sea ice bands, generation of pancake ice during freeze up in a wave field, and enhanced melting caused by waves in a field of floes.

Several wave processes that occur in the interior of pack ice were discussed. These processes include propagation and decay of swell, wind-wave generation, internal gravity waves, and flexural-gravity and sound-wave generation during ridging events. Although sufficient theoretical and observational evidence attest to the presence and importance of these processes, most of them have many outstanding scientific issues associated with them. For example, although there has been much research on long-surface-wave propagation, there is little agreement on the most important decay mechanisms and appropriate decay laws.

The effect of inhomogeneities in the ice on scattering of waves remains controversial. The effect of the wind in the supercritical condition where the windspeed exceeds the minimum phase speed of flexural-gravity waves is neither modeled nor understood. Narrowband waves near a frequency of 1 Hz have been observed many times. At the same time, the causative process and the mode of wave propagation remain uncertain. Finally, studies have only begun that use the waves as diagnostic tools to improve understanding of the physical processes.

The generation of underwater sound by mechanisms associated with ice motions was addressed. However, notable discussion was held only in the area of noise caused by floe interactions in the marginal ice zone.

Remote sensing of sea ice has had a major impact on this area of research (as it has in much of geophysics), and airborne and spaceborne synthetic aperture radars (SAR) were discussed in some detail. These instruments offer considerable insight to wave processes in ice fields because of their broad area coverage. Primary issues involve how to use information from the images to accurately estimate wave and ice properties, including calculations of dispersion curves for gravity waves.

The state of instrumentation technology received considerable attention. Most measurements of wave motions in sea ice have used rather well-developed sensor technology, such as accelerometers, geophones, and strain meters. Advances are to be expected only in evolutionary improvement of these sensors. The instruments must be deployed in more locations, in a wider range of conditions, and with more combinations of sensor types. However, specific sensor improvements can be expected only in resolution and noise level.

In the past, sensors were deployed individually or in very small numbers. New information is expected to be provided by successful deployment of arrays of the sensors. However, really exciting innovations will only occur with the advent of new instrument technologies, e.g., synthetic aperture radars. Another example is a real aperture doppler radar (Australian), which provides improved spatial information on the motions. In addition, there is an obvious application for an airborne capability of

expendable point sensors of previously developed types such as geophones or accelerometers.

This meeting successfully brought together a small community of researchers who work in this area. A first attempt was made to agree on the state of knowledge on wave-ice interactions. Although there was consensus on many issues, there was disagreement on others. As a specific area of research, the work must be considered to be in its infancy. Consequently, this workshop was able only to point out specific areas where there are obvious gaps in our knowledge. There is much to be learned. Perhaps the lasting impact of this meeting will be its use as a milestone upon which to gauge progress over the next few years.

#### REFERENCE

1. John P. Dugan, "The Music of Sea Ice—Ice Vibrations Seminar at Cambridge University," *ESNIB 91-05*, 35-39 (1991).

## Autonomous Underwater Vehicle Programs for Oceanographic Surveys and Research in the U.K.

*by J.P. Dugan and CDR John Sampson. CDR John Sampson is an ONR Europe Undersea Technology Liaison Officer at the Office of Naval Research European Office. He is an active duty naval officer from the U.S. Navy's Undersea Technology community.*

#### SUMMARY

This report reviews two United Kingdom (U.K.) programs to develop autonomous underwater vehicles (AUVs) for oceanographic surveys and research. The Natural Environment Research Council (NERC) is funding a 10-year, higher risk project with the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL) as lead laboratory. Meanwhile, the U.K. Department of Trade and Industry (DTI) is providing 5-year, 50 percent sponsorship for a consortium of Marconi, Moog, and Chelsea Instruments for a relatively low-risk, near-term development.

The DTI project has not yet been named; the NERC project is called AUTOSUB. Both projects place heavy emphasis on the AUVs as platforms for oceanographic data acquisition, in contrast to the

apparent U.S. emphasis on AUV technology without specific vehicle application. If successful, the U.K. systems may revolutionize oceanographic surveys.

#### INTRODUCTION

How are oceanographers and hydrographers going to cope with what amounts to a double whammy—the obvious need for increased amounts of in situ oceanographic data, and the increasing costs of at-sea operations? The answer from Britain is "automation."

Both the oceanographic research and surveying communities need rapid, inexpensive measurements of water and bottom properties. This is especially important in the present economic climate where the increasing expense of research and survey ships and

their operations competes for available monetary resources. Rapid eddy-resolving oceanographic surveys are needed to support

- development of ocean forecasting models,
- satellite data-gathering systems for continual data input to present and future ocean forecast models, and
- international ocean circulation and climate programs such as the World Ocean Circulation Experiment (WOCE) and the Global Ocean Observing System (GOOS).

Ships are the traditional platform from which to acquire data on the water column and bottom properties. For the water column studies, ships are used as platforms to support the scientists and technicians that collect the data. Sensitive instruments are lowered on wires through the water column to obtain temperature and salinity data and chemical and biological properties. In addition, doppler acoustic profilers are mounted on the hull to obtain water velocity data, and moorings are launched and retrieved to get time series data at a smaller number of important locations. For bottom information, the ships are platforms from which to mount, lower, or tow acoustic bottom and sub-bottom profilers and to launch bottom corers and tethered search vehicles.

A number of attempts have been made over the years to use free-swimming vehicles to improve the methodology for collecting oceanographic data. One such development in the U.S. was the Self-Propelled Underwater Research Vehicle (SPURV), which was developed and used at the Applied Physics Laboratory of the University of Washington in the 1970s. This vehicle was essentially a modified torpedo that was used to collect upper- and mid-water column data for fine-scale ocean temperature and salinity characteristics, dye diffusion studies, and acoustics tests.

SPURV was expensive to operate, and it fell into disuse. One difficulty was that it was developed and used for research only, and it was maintained as a research tool by scientists solely for that purpose. Other AUV developments typically do not have an oceanographic objective. As just one example, the large MUST AUV that was developed by Martin-Marietta and used by Martin-Perry is used exclusively as a testbed for ASW and AUV technologies.

In the U.K., oceanographers and ocean engineers have considered the present situation and the need for collecting enormous amounts of data over the next two decades as part of international projects such as WOCE and GOOS mentioned above. They

have decided to go a different way, and have begun to develop a unique capability by using AUV technology in this area. There actually are two such development programs: one in the NERC, which supports laboratories and universities, and the other in the Department of Trade and Industry (DTI), which supports industry.

## THE NERC PROJECT

The NERC project is called the AUTOSUB Community Research Project, and it is one of a number of such projects that are led by a NERC laboratory, with supporting work from other laboratories, universities, and (occasionally) industry. The funding is provided directly by NERC. It includes a portion (approximately 25 percent) that originates with the Maritime Division of the Defence Research Agency (DRA) from their "Blue Sky" funds (since they have no independent military AUV program). The funding level from all sources has been between \$1M and \$2M per year.

The AUTOSUB project was begun in 1988; the scientific coordinator was Peter Collar of the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL). It is only one of several NERC projects that have the common goals of maintaining U.K. preeminence in the world oceanographic community and simultaneously making a major contribution to WOCE. The objective of the project is to develop a versatile vehicle having two separate survey modes:

- the Deep Ocean Long Path Hydrographic Instrument (DOLPHIN) for full-depth surveys to collect physical, chemical, and biological data; and
- the Deep Ocean Geological and Geophysical Instrumented Explorer (DOGGIE) to collect high-resolution bottom and sub-bottom data.

The DOLPHIN will operate in yo-yo mode, meaning that it will cycle through the depths of interest; the DOGGIE will survey in near-bottom grid patterns. The difficulty of the yo-yo mode is that it is intended to operate over the full depths of the ocean. This requires cycling through an enormous range of pressure, and it must be done at near-neutral buoyancy so that energy is not lost in overcoming hydrodynamic lift-induced drag. A second difficulty is that the long ranges involved will require precise navigation. This is interpreted to mean periodic communications with satellites, both to obtain position and to dump some fraction of data that are

critical to the mission. Finally, an overriding consideration is total power consumption; long deployments will strain available technologies for power density and hydrodynamic drag.

The development is in the second of four phases. Phase I was a multi-institution feasibility study of the major subsystems. This study focused on several critical technology areas. These included pressure vessel design using advanced composites to achieve adequate strength and buoyancy; overall control system strategy and design; motor and propulsor design for efficient, reliable and manageable operation at great depths; buoyancy control; and energy production and management.

Phase II is the actual study of the subsystem technologies. It is proceeding now with work having been initiated on several specific subsystems. For the development of an appropriate propulsion motor, a contract was let to Moog Ltd. A prototype contra-rotating brushless dc electric motor has been designed, produced, and is now under test. It is a pressure-balanced design that involves no rotating parts other than the propeller hub, and it has no shaft seals. It is an inside-out design, with a central stator that drives the propeller hubs directly through contrarotating magnetic fields.

A detailed architecture of the prototype vehicle has been undertaken by Vickers, with an initial trade-off study of size, speed, payload, energy, and range to provide initial targets for subsystem designs. Motion studies were begun by Orchina to predict the feasibility of various ideas for recovery methods. The latter simulation was followed by tank studies at IOSDL, and this has highlighted the difficulty of obtaining reliable communications with a low-drag body in a seaway. This is an important concern because periodic communications are considered necessary for updating the navigation system, obtaining reports of system operability and subsets of the data collected to date, and providing new commands. A study by the Dunstaffnage Marine Laboratory has highlighted the negative effects of antenna washover on reception of fresh satellite ephemeris data. IOSDL also has begun a study of filament-wound carbon-fiber reinforced composites for the vehicle hull. Work has just been completed on pressure testing and assessment of water absorption of candidate composite materials.

The present conceptual design of DOLPHIN is 6-m long and 1.2 m in diameter; it has a low-drag shape with a hydrodynamic target for the volumetric drag coefficient of 0.014. The required battery supply (perhaps lithium sulphur dioxide) will take up much of the available volume.

Phase II will continue with the construction of subsystem demonstrators. Phase III will be the actual construction of a demonstrator vehicle which, at present, is expected to be a half scale model using some less risky subsystems (i.e., cylindrical rather than low-drag shape). Design of this demonstrator vehicle will be a sensitive balancing act between minimizing risk and adequately demonstrating new technologies in the field. Within projected funding, first deployment of the demonstrator is not expected until 1995.

This development is especially interesting because of the stated requirement for collecting oceanographic, geological, and geophysical data over large areas. To effectively carry this out will require many of these vehicles and an infrastructure of support services. John Woods of NERC projects a need for 100 AUVs and their support services to support WOCE and follow-on global ocean observational activities, and he acknowledges the magnitude of the challenge.

One interesting component of this program is the emphasis on scientific input to goals and decisions, and on maintaining good communications between scientists and technologists at all stages. To this end, IOSDL has held a series of workshops, and the laboratory produces and distributes an occasional newsletter called *Nautilus* that provides up-to-date information on the progress of the project. It is available by writing Peter Collar at IOSDL, Brook Road, Wormley, Godalming, Surrey GU8 5UB, U.K., calling him on +44 428 684141, or passing a message to him on omnet via IOS.WORMLEY.

## THE DEPARTMENT OF TRADE AND INDUSTRY PROJECT

The second AUV development program involves the Department of Trade and Industry (DTI), which is providing seed money at approximately the 50-percent level to a consortium of Marconi Underwater Systems Ltd, Moog Controls Ltd, and Chelsea Instruments Ltd. The DTI funds are provided under their Wealth From the Oceans Initiative in the Advanced Technology Programme. To date, the vehicle does not have a name. The objective of this effort is to develop an AUV of similar but more limited goals compared with the AUTOSUB program. Concomitantly, this will enable the use of less risky and less expensive technology. The idea is to develop a device that will provide stimulus for a market in the near future, and to improve it incrementally. In the meantime, it definitely is a loss leader for the consortium. To minimize the risk, this group will use

technology that presently is available, beginning with Marconi's 21-inch heavyweight torpedo, a technology that is available from military applications.

The preliminary design goal has the following characteristics: 300-kilometer range, 35-hour endurance, 5-knot speed, 300-meter maximum depth, 6.5-meter length, and 1.3-ton weight. These resulted from a much shorter preliminary design study that built in part on results available from the AUTOSUB program. Total projected costs are expected to be \$15M over the four-year development cycle.

The prototype vehicle is a demonstrator to be deployed for first seatests at end of March 1992. The actual vehicle was on display at the Oceanology International '92 (OI92) meeting in Brighton, U.K., in March. This vehicle also will have two standard mission profiles. A yo-yo from the surface to 300-meter depth will be used for oceanographic missions, and a straightline run for under ice and bottom survey missions.

The hull is made entirely of standard ex-torpedo hull parts, with the addition of a small external keel for increased roll stability and larger tail fins for control. Major subsystems are navigation, energy, propulsion, and payload. Navigation at this stage is by dead reckoning, so it includes only speed and compass measurements.

A reasonably complete review was made of available high-energy density sources, and the results were reported by Marconi at the OI92 meeting. For the projected mission profiles of this vehicle, the minimum energy requirement was found to be 36 kWh with a density of 100 Wh/kg. Only primary and secondary (rechargeable) electrochemical batteries satisfy the need for an off-the-shelf availability; and a secondary battery was chosen because of cost effectiveness. The specific battery has sodium sulphur cells that were originally designed for potential electric road vehicle use. These units require elevated temperature in the 290-350 deg C range to liquify the sodium, so the battery management subsystem must include temperature controls. In practice, the projected missions are short enough to require little or no heating beyond that provided during the deck-side charging operation. On the positive side, they have a constant voltage discharge curve, no secondary reactions or gassing, and simple logic for charge monitoring. The batteries chosen for the task are assembled from a series-parallel combination of pilot production cells available from Asea Brown Boveri in Germany.

The drive motor design has been driven by the requirement for high efficiency, high reliability, and

serviceability without having to open watertight seals or housings. The result is a new Moog Controls Ltd. brushless dc motor, which also was presented at OI92. The motor has a rotating outer motor, inner stator, seawater-lubricated bearings, no rotating shaft seals, and separate full-wave trapezoidal wave control and power electronics. The design has motor efficiency of 92 percent and controller efficiency of 90 percent. It has been built and presently is under test.

The sensor system will be a combination of oceanographic instruments and an upward-looking side-scan sonar. The sensors are being developed by Chelsea Instruments Ltd. They contain a newly designed, distributed data acquisition and storage system, which also was reviewed at OI92 (the written paper is obsolete, but up-to-date information is available in an unpublished handout that Chelsea has provided). The subsystem uses separate microcomputers at each sensor to minimize the opportunity for any one failure to bring down the whole system. The modules then communicate with the master controller on serial lines for both set up and dumping the data. Projected sensors are temperature, conductivity, depth, chlorophyll a, dissolved oxygen, pH, and other sensors either currently available or being developed by Chelsea.

Phase I of the development ends when the vehicle is ready to go into the water. Phase II is one year of inwater tests, and phase III is the initial demonstration during oceanographic experiments next spring. These first deployments for oceanographic measurements will be in March 1993, with a series of 100-kilometer excursions under the Arctic pack ice from the HMS *Newton* during the Greenland Sea Project. This is to be followed by similar deployments during the Scoresby Programme.

In comparison with AUTOSUB, this vehicle has a tighter development time line (i.e., three years instead of ten), but it has much more limited goals (i.e., no low-drag shape, no full-dep'n range, no long duration, dead reckoning navigation only). Also, instead of an aggressive (but in my view tenuous!) plan for many tens of AUTOSUBs with a full infrastructure of support services, this one is expected to be deployed in small numbers from a mother vessel. One projected mission being discussed is full time- and space-resolved mesoscale surveys.

The technical representatives of the companies made lots of original claims for this vehicle during the OI92 meeting in Brighton, although this is not unusual for new developments. It is in keeping with the importance of the project, because it will demonstrate at an early date the utility and real costs of

using an oceanographic measurement system of this type. It is really exciting to see such a strong emphasis on an oceanographic application of AUV technology.

## DISCUSSION AND CONCLUSIONS

Several other developments in the U.K. are closely associated with these vehicles. There is an opportunity for IOSDL and DRA to collaborate in a European Community initiative as part of Mast II (marine science and technology) on a more general project associated with underwater vehicles. In a proposal currently under review, funds would be made available to these groups as well as organizations in Greece and France for EC-funded research and development. In addition, NERC has extended an announcement of opportunity for a Special Topic, which will fund the development of novel instruments for, among other applications, the AUTOSUB scientific payload. This will address the design of a new generation of instruments that will be suitable for long-term autonomous deployment. This effort is being called SIDAL, which is an acronym for Scientific Instrument Development for AUTOSUB and LOIS (Land Ocean Interaction Study). It is to be funded at about \$1M spread over 3 years and headed by Prof. J.H. Simpson of University College North-west Wales, Bangor.

These U.K. developments are interesting from several standpoints. First, they clearly focus on oceanographic data collection, as opposed to the

more usual focus of military or oil production needs of search, inspection, etc. It is interesting to see such a strong emphasis on an oceanographic application of available and developing AUV technology. On the other hand, as with other marine environmental projects, these groups have only a fraction of the resources that are available to typical U.S. Navy programs in NavSea, ONR/ONT, and DARPA. Thus, we expect that the British will be in the position of taking advantage of every technological advantage that they can get their hands on. How they will optimally incorporate the best that is or will be available in this rapidly changing field over the next few years will be a real challenge.

These oceanographic instrumentation developments are worth following closely because they will provide important lessons on how to apply available and emerging AUV technologies to revolutionary new techniques of oceanographic data collection. New applications and ideas are being developed as fast as oceanographers and instrumentation engineers open their minds to the possibilities. Ten years from now, we believe it is very likely that one of these developments will provide oceanographers and hydrographers with a classic example of "why didn't we think of this before?" On the other hand, just like SPURV, there is a finite chance that they may turn out to be too costly to operate and difficult to use, and they may top the list of failed oceanographic instrumentation developments as the most expensive ones ever.

## Airborne Capabilities For Boundary Layer Turbulence Research—Unique United Kingdom Capabilities

*by J.P. Dugan*

### INTRODUCTION

With its C-130 aircraft facility at RAF Farnborough and tethered balloon facility at RAF Cardington, the Meteorological Office in the United Kingdom (U.K.) has unique airborne instrumentation for contributing to research in the atmospheric boundary layer. These facilities collect data to validate models of boundary layer processes that are

important for Navy programs. These processes have applications to optical wave propagation near the sea surface, ship cloud wakes, and other phenomena.

The boundary layers near the sea surface are important to the U.S. Navy because most operations at sea are influenced by them. They are an integral part of meteorological and oceanographic forecasts; they impact the performance of detection and weapon systems operating either near the surface or

where the surface is in the field of view. These boundary layers also are important in the wider context of global climate, since the ocean provides such a large driving and moderating effect on the atmosphere.

Thus, it is not surprising to find that the U.K. has a significant research effort in this area. What is surprising is that the research activities reviewed here have no real counterpart in the U.S. Thus, they offer an opportunity for comparison and, perhaps, for fruitful collaboration in the future.

This report provides a background as to how activities in this area fit into the overall structure of boundary layer research. It provides a review of the capability and relevant activities of the Meteorological Research Flight (MRF) Unit at RAF Farnborough and the Meteorological Research Unit at Cardington. Both units are field research offices of the U.K. Meteorological Office, whose headquarters is in Bracknell west of London, not far from the large Meteorology Department at Reading University.

Most interesting to us, these units provide world-class, unique "national" facilities for boundary layer research, and they have important applications for research in the maritime boundary layer. Because the Meteorological Office is an Agency of the Ministry of Defense (MoD), units have direct impact on Royal Navy needs. There are no direct counterparts in the facilities presently available to researchers in U.S. Navy laboratories who are working in this important area.

## **ATMOSPHERIC/OCEANIC BOUNDARY LAYER**

The boundary between the atmosphere and the ocean is an extremely complicated region that couples the two environments. The interaction between air and water affects meteorological conditions markedly because of heat, moisture, and momentum fluxes. To a large extent, the atmospheric circulation is driven by these fluxes through their strong influence on synoptic-scale processes.

Simultaneously, these same fluxes determine the ocean surface layer conditions, and they drive the general ocean circulation. Although the two problems have long been decoupled by researchers by simply making this assumption, they are in fact irrevocably coupled, and modern prediction models must take this into account.

An improved level of understanding of the physical processes in these boundary layers is important to many Navy systems, since increased knowledge is

a prerequisite to better predictions. There is an obvious need to provide better predictions of the "weather" at sea to support normal operations of surface, air, and subsurface forces. However, there is an additional need by modern forces for accurate environmental predictions to support the sophisticated detection and tracking algorithms in their offensive and defensive weapon systems.

As an example, the basic kinematic forms of the surface boundary layers are of fundamental importance to Navy systems that are designed to detect objects on or near the sea surface. The depth and structure of the mixed layer in the water determines the sound velocity profile and, therefore, the performance of acoustic detection systems for submarines operating near or in this layer.

In an entirely analogous way, the state of the surface atmospheric boundary layer determines the vertical structure of the index of refraction profile, and this affects the performance of surface-ship missile-defense radars. In both cases, the vertical profiles of wave speed are a direct input to propagation models for predictions of sensor performance.

These boundary layers are not well mixed, but they have significant thermal and other fluctuations that are important in various ways to detection systems. The turbulence that mixes and (nearly) equilibrates the physical variables in the layers in fact supports the net heat and mass fluxes through fluctuations of these same variables. Thus, in detail, there are very important fluctuations in the sound velocity and index of refraction in the layers. These cause modulations in the receivers of detection systems, and these modulations are a source of environmentally induced noise in the detection and tracking system.

Additionally, the stress on the ocean surface by the wind in the boundary layer generates waves that affect the performance of detection systems. For prospective targets near the surface, the waves provide a source of clutter in receivers in which the signal must be detected. For hydrodynamic signals such as ship or submarine wakes, the waves are not only a source of clutter, they are also important in the evolution of the signal.

## **RESEARCH IN BOUNDARY LAYER PROCESSES**

Significant research problems are associated with improving our understanding of the structure of these boundary layers. The goal of these efforts must be to provide improved predictions of the performance of detection systems. However, this task is

complicated by the very nature of the undertaking. The research must result in better predictions of simple gross parameters like the depths of the layers and the strength of any mean internal gradients.

In addition, however, it must provide better predictions of the expected signal-to-noise level of specific systems whose performance is limited by environmental noise. In either case, significant future improvements in the accuracy of predictions will come only with advances in our understanding of the physical processes that are occurring in the boundary layers.

As mentioned previously, the research in air and water layers has traditionally been decoupled, enabling simpler representations of the problems to be solved. The research typically has been performed either by oceanographers interested in the upper ocean or meteorologists interested in the lower atmosphere, and they often work in separate departments or laboratories (e.g., separate locations of these specialties within the structure of the Naval Research Laboratory). It is not uncommon, even today, for a meteorologist or oceanographer to specify the "surface boundary conditions" and consider only the results on the dynamics in their one-sided model.

Further progress toward improved predictions is often made by decoupling, but since the layers are closely coupled in nature, consideration must be given to coupling them in the models. This is acknowledged by the research community, and work is proceeding with a combination of modeling and observations.

## PHYSICS AND MODELS

Researchers begin to understand a physical problem if they are able to establish a set of equations that represents the dominant processes that occur. This set of equations, the dynamical equations of motion, is a fundamental component of any model, and there are several general categories. One, called a processes (or physics) model, is useful in research activities directed toward an improved understanding of the processes themselves. The other is called a predictive (or dynamical) model; this is used in an operational mode to make predictions as to what the physical state will be sometime in the near future.

These models are almost universally some representation of the laws of physics in the form of differential equations. They are coupled partial differential equations, meaning that several unknown variables (velocity, temperature, pressure, for instance)

are related by their derivatives at every point in space and time

These equations require initial and boundary conditions for their solution. The differential equations typically are replaced by a large but finite set of algebraic equations that approximate them at many grid points in space. Values of the unknown variables are specified initially at all points and continually on the boundaries, and the solution of the equations are stepped forward in finite intervals of time.

The equations of motion are well known, but the real complication for environmental problems of this type is that the all-important spatial scales cannot be resolved simultaneously. There is not enough computer capacity to encompass the whole of the boundary layer while simultaneously resolving the smallest scale that is determined by the turbulence dissipation scale.

The whole layer is important because the fluxes are imposed at least in part by processes that occur in the vicinity of both the upper and lower boundaries. The real science here is in how the full spectrum of turbulence scales can be incorporated at a finite number of grid points. How to accurately represent the processes that are not resolved by the grid spacing (called the "sub-grid-scale" processes), is a major technical issue in its own right, and this has become the focus of a rather important subdiscipline.

The process research model is used as a computer laboratory to perform simple experiments. Initial and boundary conditions are specified for some specific situation that is designed to elucidate a particular phenomenon. A model "run" is initiated, and the results are analyzed much like the results of a laboratory experiment, informing the researcher as to the phenomenon under study. For complicated problems, the success of this approach is proportional to the inventiveness of the researcher, and includes the cleverness of the manipulation of the resulting model "data."

Following the methodology of scientific research—modeling ever more complicated situations—the environmental modeler learns more and more about the physical processes occurring in the boundary layer. This type of modeling is often done independently of any experiments in the real world, but the reality of the assumptions in the models is always a matter of concern. Thus, observations (sometimes inappropriately called "experiments") at full scale, and the analysis of data from the real ocean/atmosphere, are of great interest to these modelers.

A capable predictive model is necessary to provide products that ultimately will be of benefit to the

fleet. This type of model must incorporate simple but effective representations of the physical understanding that has been discovered from the above-described type of analyses. However, this type of model requires additional components, and these are an accurate assimilation technique for field data and efficiency so that they can be run faster than real time.

The assimilation is necessary because the differential equations admit chaotic solutions, and the solution eventually will depart from reality, no matter how accurate the initial and "boundary" conditions. Data from the real world must be available to update and re-start the solution procedure periodically before it departs too far from reality.

The accuracy of the prediction-type model is a matter of significant concern, so there must be "experiments" in which the model is run in parallel with a large data collection effort, and the results compared. The skill of the model is measured by its closeness to the observations at specified times in the future. Only models of high skill are useful for predicting the future state of the boundary layers. They must, of course, run faster than real time, on computers that are currently available (or will be available in the future) or they will be of little practical utility.

## DATA REQUIREMENTS IN THE ATMOSPHERE

Observations are a key ingredient to measuring the skill of the models and to the continual running of predictive ones. Here again, the specific type of data, and the instrumentation requirements for acquiring them, differ markedly—depending on the use. Experiments for physics models might attempt full resolution of all scales of importance in a specific synoptic situation of interest. Those for predictive applications must be able to estimate their skill over a much larger time and space domain.

Present concerns involve designing appropriate experiments, with the accompanying requirements for collecting and analyzing the environmental data. Typical requirements are for measurements of surface fluxes and kinematic state (depth, turbulence level, etc.) of the boundary layer over the synoptic scale.

## INSTRUMENTATION

For continuous atmospheric boundary layer data at a single location, ships and buoys are a time-honored mode of collection. Admittedly, they suffer a

number of problems, including "blockage," motion in a seaway, and above all, lack of quick response to movement of synoptic systems. However, research vessels provide a convenient place to locate scientists and sophisticated instruments like remote sensing profilers. Radiosondes can be launched periodically, and sounders can provide continuous vertical profiles. Also, balloons can be tethered from ships, thereby providing very detailed profiles of turbulence quantities.

Aircraft are an extremely important component in acquiring research data on the state of the boundary layer. They can make direct measurements of the fluxes of momentum, heat, and moisture, and they can do it (albeit for only limited periods of time) over the entire synoptic scale. If the measurements are close enough to the surface, the atmospheric fluxes must be balanced by fluxes in the water, and the measurements provide a strong control on the subsurface data set as well. In addition, aircraft are convenient platforms for remote sensing profilers.

The remainder of this report focuses on tethered balloon and aircraft facilities in the U.K.

## METEOROLOGICAL RESEARCH FLIGHT

The Meteorological Research Flight (MRF) is a field research activity of the U.K. Meteorological Office and is presently located at RAF Farnborough, which is also west of London. The location is dictated by the unit's unique research facility, the "airborne laboratory," which is a dedicated, instrumented Hercules C-130 aircraft. The unit's primary purpose is to ensure that the Meteorological Office's services and products benefit from improved knowledge in physical processes in the atmosphere.

The primary Meteorological Office product is the familiar weather forecasts, but also included are climate predictions; in either case their accuracy is dependent on numerical models. MRF supports this primarily by experimental studies of key issues of atmospheric processes and their representation in models. The unit also provides expertise to the wider meteorological community and direct input to other services and products.

The unit is one of two field activities in the Atmospheric Processes Research Division of the Meteorological Office, the other field activity being the Meteorological Research Unit at Cardington. The current Chief Executive of the Meteorological Office is Professor Julian Hunt. The Director of Research is Dr. Paul Mason, who has a background in boundary layer dynamics. The Deputy Director

for the Atmospheric Processes Research Division is Dr. Peter White. One of two Assistant Directors is Dr. Geoff Jenkins who heads MRF, which is a Branch in this Division. Figure 1 is an organizational chart.

MRF has about 50 personnel, of which six are dedicated uniformed aircrew, about 20 are civilians in a facilities group, and the remainder are scientists associated with the research activities. Figure 2 shows the organization of the unit. The Facilities group provides measurement support for the aircraft, computing services, and instrument calibration and maintenance services. This group is organized to take full control of the data collection and preprocessing, including quality checks and calibrations that transform the data into physical units.

The Microphysics, Radiation, and Chemistry groups are all presently at Farnborough, and the Mesoscale group is at the University of Reading. The primary effort of the Microphysics group is to understand the structure and evolution of clouds, with the goal of improving the representation of clouds in both weather and climate prediction models. (It previously was led by Dr. Steven Nickolls, who was widely known for his work on turbulence in the maritime surface boundary layer and on clouds, but who unfortunately passed away.) Dr. Douglass Johnson leads the group in more recent work in cloud physics.

The primary effort of the Radiation Group is to understand and parameterize the fluxes of solar and infrared radiation in both cloudy and cloud-free air. Their goal is to improve both the representation of fluxes in models and atmospheric retrievals from satellite data. The primary effort in the Chemistry group is to understand the generation of tropospheric ozone and to improve the representation of photochemistry in models. Finally, the primary effort of the Mesoscale group is a better understanding of the genesis and development of mesoscale systems such as fronts, with the goal of refining their representation in forecast models.

### THE C-130 AIRBORNE LABORATORY

The aircraft is a Hercules C-130, whose most obvious modification is the long nose probe and relocation of the radar dome. It has a range of 5500 km, a duration of up to 11 hours at speeds of 75-150 m/s, and altitudes from 20 to 10,000 m. The large hold provides sufficient space for up to 15 scientists to operate and maintain the many sensors. The aircrew of two pilots, navigator, engineer, and loadmaster are military personnel attached to the Unit,

and they contribute considerably to the success of the unit because of their experience in research flights. They are dedicated to operation of this single aircraft for the duration of their assignment to MRF. A distinct advantage of a C-130 over a P-3 in particular is that there is room on the flight deck for a chief scientist seat, and this one is well-equipped and has a wide field of view.

The measurement system is reasonably typical of those on meteorological research aircraft today. Its 12-m long nose boom was designed after studying the potential flow disturbance by the aircraft. It uses gust probes that are mounted near the tip to measure wind relative to the aircraft. These probes are similar to ones used in the NASA ER-2 meteorological system for measuring angle of attack and sideslip (although that aircraft has recently changed to pressure sensors on a rounded nose cone as currently used by other U.S. researchers, such as on the NASA CV-990 and the NCAR Sabreliner). MRF presently also is studying a change to a pressure-measuring system to replace the vanes.

All these systems must account for the aircraft motions, and for this they use inertial systems (a Ferranti FIN 1012, which was broken during one of my visits to MRF). All inertial systems have well-known limitations; they are especially error prone for the horizontal wind components resulting from drift caused by Schuler oscillations. This results in low-frequency windspeed errors of up to 5 m/s. This magnitude is reduced to below 1 m/s by simultaneously processing Loran C and other (standard) navigation data. This has recently been further improved by the installation of a Global Positioning System receiver.

There is a complete suite of other instruments. Temperature is sensed by two Rosemount platinum resistance thermometers (one heated to prevent icing) and an in-cloud temperature probe. Humidity is measured by using a chilled mirror hygrometer for low frequencies and a Lyman-alpha absorption device for high frequencies. A microwave refractometer also is available for direct estimates of the index of refraction. An absorption fluorescence Lyman-alpha device providing high-frequency response and high accuracy is being developed in-house. There are a number of radiometers, including a narrow-beam Barnes PRT4 surface-temperature thermometer, upward- and downward-looking short- and long-wave broadband radiometers, a scanning visible and longwave narrowband radiometer (16 channels), and a scanning microwave radiometer.

In addition, for cloud physics research, there is a comprehensive suite of instruments for measuring

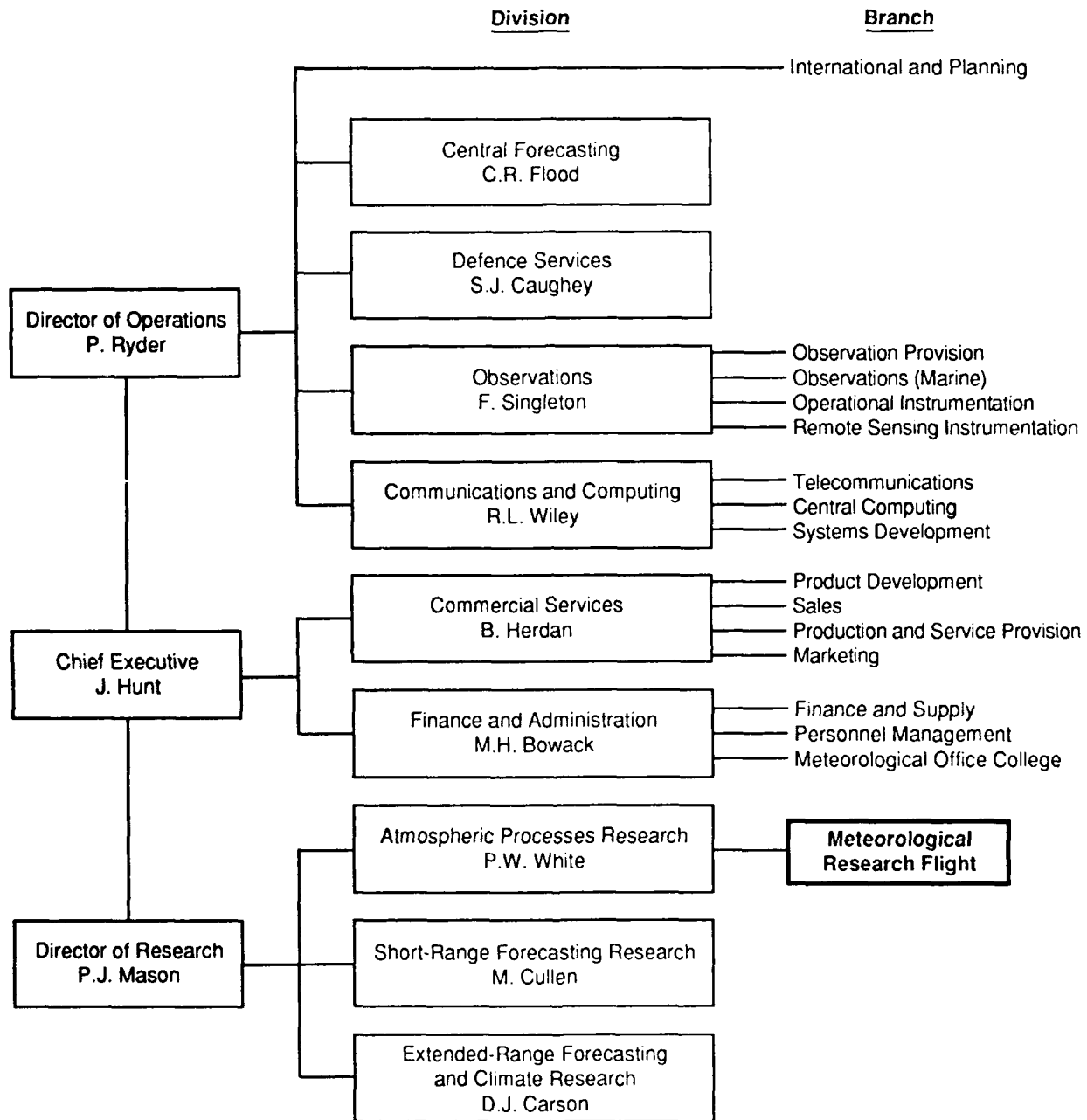


Fig. 1. Meteorological Office Headquarters Organization

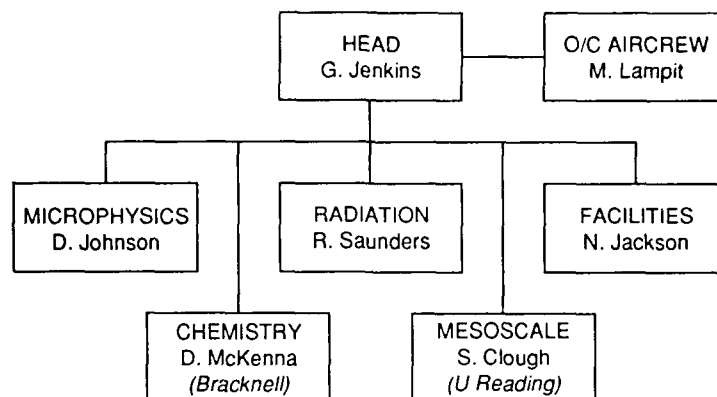


Fig. 2. Meteorological Research Flight

cloud particle size distributions and water content. There are 2-D optical array probes, a forward-scattering spectrometer probe, a passive cavity aerosol spectrometer probe, a liquid water probe, total water hygrometer, and a holographic imaging system for particulates. The latter is a powerful tool, but it requires a massive amount of manual labor in image reduction to obtain distribution functions. In addition, there is aerosol sampling equipment in the form of an integrating nephelometer and a cloud condensation nuclei counter. For chemistry, there are bottle samplers, an ozone analyzer, and numerous other chemical detectors.

The aircraft has a dropsonde capability to measure profiles from flight altitude to the surface. These instruments are dropped out of the aircraft on parachutes, and they measure winds by Loran C navigation receiver and use typical sonde sensors for temperature and humidity. Data can be received from five of them simultaneously and from a total of 60 sondes per flight, so the system can be used to provide quasi-three-dimensional measurements of the mesoscale and synoptic weather system. The turnaround between launches is three minutes; this provides about 25-km spacing. Unfortunately, it also requires three people to operate—a computer system operator, a dropsonde handler, and an ejector operator.

Data acquisition for all these sensors on the aircraft is provided by a microVax with a microcomputer data interface. Individual data channels are selectively sampled at from 1 to 64 Hz and recorded on optical and hard disks. The computer carries out real-time demultiplexing and calibration, and presents the data to the operator in any of a number of selectable displays, including numeric listings, time series, tephigrams, hodographs, and tracks.

Hardcopy is available for use during the flight. In the routine but quick post-test processing, the performance of all sensors is assessed. Track plots are generated so that rapid decisions can be made regarding the data, progress of the operation, and detection and isolation of any problems that may have occurred. Bad data segments are flagged for automatic recognition in post-test processing. A standard set of library routines is available for analysis of the data sets, both onboard the aircraft and in the laboratory.

Before leaving the subject of this platform, it is important to note that these instruments and the data acquisition system are permanently fitted to the aircraft, and they are periodically tested and calibrated by the facilities group. This has the decided advantage of freeing the scientists from this never-ending chore. In addition, it guarantees that maintenance and calibrations are done the same way for every flight over very long periods of time, thus easing the burden on the scientist of maintaining control over the configuration of hardware and software.

### C-130 DEPLOYMENTS

Meteorological Research Flight has been a major component of many international research experiments, including marine surface layers in the Joint Air-Sea Interaction Experiment, persistent stratocumulus off the California coast in the First International Satellite Cloud Climatology Project Regional Experiment, and microphysics and radiation in cirrus over the North Sea in the International Cirrus Experiment (ICE), to name just a few.

The aircraft was deployed on short notice to the Arabian Gulf just after the end of Desert Storm in March 1991 to make measurements in the smoke

plume from the massive oil fires. The results of those observations were published very quickly in *Nature*. MRF will be participating in FRONTS '92 and in ASTEX near the Azores among other planned experiments.

### THE METEOROLOGICAL OFFICE RESEARCH UNIT AT CARDINGTON

The research unit at Cardington is a second field activity of the Atmospheric Processes Research Division; it is under the second Assistant Director of the Division, Dr. Nigel Thompson. The field activity is headed by Dr. Philip Hignett, who has a background in small-scale physical modeling of stratified, rotating fluid systems. The goal of this unit is to provide boundary layer measurements for model validation, and its primary measurement facility is its instrumented tethered balloon.

The unit has four scientists (including Dr. Hignett), six technicians, and three mooring crew. The facility is located at RAF Cardington in the Midlands. It is largely unoccupied today, but it was the location of a large balloon (and dirigible) facility during the first half of this century. There still are two very large hangars, one of which is used to protect the research balloon. The hangar also contains support shops, but the staff of the research unit is housed in a small two-building complex with offices and instrument laboratories across an open field some distance from the hangar.

The airfield is on a broad, low-relief plain, so it can be used for many experiments on boundary layers over land. It is a good location except on occasions when the wind direction is from the quadrant of the hangars. There is a small complex of one mobile and two fixed masts that provide the usual profile and flux data for on site observations. These include point sensors for wind, temperature, and humidity (at 1/2, 1, 2, 4, and 8 m height), radiometers, a sounder, and a ground station for radiosonde materials.

The primary facility is the balloon instrumentation that is composed of a large helium balloon, which provides lift, and up to ten instrument pods attached to the tether cable. The balloon size is 24,000 cubic feet, which provides 600 pounds lift at the surface; it is raised and lowered from a special winch mounted on a truck bed, the "mooring lorry." Each instrument pod measures three components of velocity, temperature, and humidity and weighs about 20 pounds.

These measurements, together with motion and housekeeping data, are telemetered via VHF data links to a ground receiving and recording station

located in an instrumented van. The data are sampled at up to 20 Hz with a microVax data acquisition and processing system. Software has been developed for all the standard quality checks, calibration, logging, and near-real-time processing and display.

This unique capability for measuring turbulence is provided by an ingenious sensor design. Three components of velocity are measured by using Gill anemometers mounted forward of the cable. The attachment method permits the anemometer mount to swivel into the wind to avoid interference with the mooring cable. The direction of the mount is driven by a trailing wind vane, and it is sensed by magnetometers. The relative velocity components are then calculated from the anemometer and direction measurements and the (nonorthogonal) anemometer direction cosines.

However, the real breakthrough is in the special way that corrections are made to the data for the inevitable motion of the balloon and cable in the same turbulent atmosphere in which the measurements are being taken. The motion sensors in each pod measure two components of tilt by using horizontal accelerometers and three components of orientation by using a 3-D flux gate magnetometer. The major sources of sensor motions are the cable vibration due to aeolian tones, the natural modes of vibration of the long tether and attachments, and the balloon motions in the turbulence at its altitude. Corrections are accomplished by a complicated algorithm.

The cable "buzz" at 10 Hz and above is removed by simple low-pass filtering; the only concern in this band is that the motion sensors respond linearly at high frequency so that rectifications of the very high accelerations do not occur. The transverse modes of vibration of the cable occur in the 0.05-0.5 Hz band. These are due to the distributed mass of the whole cable and to the multiple sensor attachments. They are a serious problem because they cause large inclination errors as the result of spurious accelerations.

The success of this group is due to the methodology they developed to subtract these cable-induced motions from the anemometer measurements. Finally, the low-frequency band of 0.01-0.02 Hz is due to pendulum motions of turbulence acting on, and dynamic instabilities of, the balloon. However, these cause few technical problems since the inclinations are not affected by the accelerations.

The balloon can be used at locations removed from Cardington. The balloon is deflated and transported with about 50 tons of equipment, including gas bottles for deployment at remote sites. The unit has successfully done this in experiments on the

dynamics of the boundary layer in rougher terrain. A deployment to the Black Mountains in South Wales, with hill height of about 500 m, has provided several interesting results. The surface roughness length, which is necessary for parameterized surface stress in numerical models, has been calculated for various stability conditions by both the drag coefficient and separate analysis of wind profiles.

## CONCLUSIONS AND COMPARISONS

One very interesting feature associated with these field units is their position in the organizational structure, especially as it relates to the Meteorological Office and the Ministry of Defense (MoD). The relationship is unlike any in the U.S. Because the Meteorological Office is an agency of the MoD, there is a shared interest in the final operational product, namely the weather forecasts. However, even in the research end of the business, where these units reside and where the issues are related to improvements in the weather product. There is an especially close relationship because of the direct investment by the RAF in the costly aircraft, flight personnel, and the shared facilities at Farnborough and Cardington.

The result is that the Meteorological Office, the MoD, and university research programs all benefit from having available common "national" facilities for meteorological research. Because both units have first-rate turbulence measurement capabilities, they are excellent facilities for boundary layer research. MRF has a long history of research in the marine boundary layer, but the Cardington capability also could be applied to that arena; the result is that the British have a strong capability in the discipline.

Because the U.S. Navy has significant boundary layer problems to be solved, the interesting question arises as to why we do it so differently. In particular, research aircraft are not dedicated to specific disciplines in the Navy laboratories, but are available on a project-by-project basis to many disciplines and research projects. (This also applies to most research aircraft outside the Navy.) This has cost benefits because it maximizes utilization of the research facilities by all Navy projects. The result is that a number of aircraft are available for any specific project part-time but, unfortunately, none of them are fully instrumented.

Researchers must budget, schedule, and install their instruments in the aircraft each and every time they use it. Then, the scientist typically does not install as many sensors as normally are available on the C-130, simply because of the enormous task of doing so. Of course typically not all of the sensors

that are on the C-130 are needed, but research necessarily suffers by their not being easily available. In addition, the researcher cannot respond to rapidly changing requirements or to unique opportunities such as the deployment of the C-130 to the Middle East to survey the Kuwait oil fire plume. This was an extremely important opportunity; it was the largest anthropogenic heat and particulate source available to date to test wide-area, low-altitude dispersion models, and only MRF was able to respond quickly.

An additional but very important advantage of the standing facility is that the researcher benefits from a regular data quality and preprocessing system. These tasks are performed quickly and efficiently; researchers do not have to turn their full attention to them. They can get on with their research, knowing that the "system" will do its best in supplying quality controlled, calibrated data.

Is there a way to learn from this? Should we in the U.S. have capabilities like these? How can we best take advantage of the ones that exist here? These really are meant to be rhetorical questions but, if pressed, I certainly could not supply answers to them. Perhaps this exposure to a wider audience will lead to further discussions and informed decisions in the future.

One specific but rather obvious recommendation is that U.S. scientists involved in research in boundary layer processes should be acquainted with this capability and should take advantage of it where appropriate. This may be accomplished by communicating research plans to a wider audience so that the community can take advantage of all opportunities on an international scale. As an example, multiple aircraft are often involved in air-sea interaction experiments because many sponsors and researchers have overlapping goals.

A second, more direct way, having somewhat more limited goals, is to take advantage of the systems already in place here. Because these systems collect data for very specific but many different applications, they accomplish a very high rate of data collection. The result is that more opportunities for research using the data are becoming available for projects that have different objectives than those of any specific data collection flight.

## Point of Contact

Meteorological Research Flight  
Royal Aerospace Establishment  
Farnborough Hampshire  
GU14 6TD  
United Kingdom  
(Attention: Dr. Geoff Jenkins, Head)

# United Kingdom Capabilities for Synoptic Surveys of the Ocean

by J.P. Dugan.

## OCEAN FLUCTUATIONS AND UNDERWATER ACOUSTICS

The ocean synoptic scale, which comprises eddies and fronts, is important for long-range acoustic propagation. However, accurate measurements of this scale that are suitable for propagation modeling are extremely difficult to make. This report discusses advances in oceanographic instrumentation in the United Kingdom (U.K.) that promise to make this job easier.

The ocean displays fluctuations in its density and velocity structure over an enormous range of scales and frequencies. The largest length scales, those of the mean circulation, are determined by the basin size and shape, as well as by the heat exchange with the atmosphere and the lateral stress of the winds. This circulation exhibits annual and interannual fluctuations associated with changes in the forcing. In addition, it is not stable dynamically and it spawns many oceanic features that are synonymous with synoptic weather patterns in the atmosphere.

Horizontal sizes of these features are tens to hundreds of kilometers and, because of the weather analogy, the motions are termed *synoptic*. The term *mesoscale* is often used and fronts and eddies make up the dominant features that are recognizable as analogs of synoptic systems in the atmosphere. Finally, the ocean also exhibits several smaller-scale processes such as surface waves, internal waves, turbulence, and fine and microstructure.

The frequencies associated with the motions on these different spatial scales are determined by their dynamics. Time scales range from months to years for annual and interannual changes in the mean circulation. They are days to months for the synoptic systems, and the time scales are as small as seconds for surface waves and the microstructure.

All of these motions are important to acoustic propagation in the sea. Generally, the longer scales are more important to long-range, low-frequency propagation, and the smaller scales to higher-frequency acoustics. For long-range propagation, the synoptic scale is important. The scale represents the largest fluctuations in sound velocity, and this determines the location and magnitude of illuminated zones from any sound projector. Therefore, it deter-

mines the tactical acoustic situation. It appears possible to resolve the synoptic scale in oceanographic analysis and prediction systems. To this end, U.S. Navy and NATO oceanographers have been involved in measuring and modeling the fronts and eddies on the synoptic scale.

## MODELS

For acoustic propagation studies, dynamic models of the ocean fluctuations actually are useful for several reasons. They are used to study the importance of the oceanic variability on the acoustics. For instance, computer experiments are run on model ocean fields to determine the important time and space scales of the acoustic field. Also, an ocean model may be used to indicate areas of high activity. As the oceans have not been surveyed everywhere on fine enough spatial scales to resolve the synoptic fluctuations, the models are useful for predictions of regions and energy levels of eddy activity.

In each of these cases, the model can be run for long periods of time—even with crude initial and boundary conditions. Also, the output is studied for areas of high and low synoptic activity. The Gulf Stream system is an example of an active region that is easily accessible to U.S. east coast oceanographers. Therefore, it has received more than its fair share of attention by oceanographic and acoustic modelers.

The oceanic fields that are output from this type of model can be used directly in acoustic propagation modeling. The results provide an indication of the importance of the oceanic variability. This use of the models is entirely consistent with a non-Navy application—climatic studies of the ocean circulation. This is important because the synoptic scales are dominant features in heat and momentum fluxes in the ocean. Because of the climatic utility, the models are undergoing extensive research and development (R&D) by several institutions around the world as part of the World Ocean Circulation Experiment Program.

Another very important application of the models is to predict this oceanic weather at a particular location and time, which is a primary goal of Navy oceanographers. It is also of interest in climatic studies but only for testing, validation, and tuning of

models with real data, since there is no concomitant ongoing requirement for real-time predictions as in the Navy application. For the predictions, a model is used, along with assimilated initializing and updating observations, to make specific predictions of the thermocline structure in the particular area of interest from the present and for up to a month or more into the future.

## OBSERVATIONAL REQUIREMENTS

A fundamental weak point in this whole developmental area is that the observations for initializing and running these models are not readily available. Not only are they not available on a regular basis, they generally are not available even for test cases that are run to assess the accuracy of the models. The hope is that remote sensing in the form of satellite images and other data will save the day.

Presently, even the correct interpretation of satellite data in terms of three-dimensional (3-D) sound velocity fields requires algorithms of some complexity and untested accuracy. These in turn, require some in situ observations on the ocean density, temperature, and velocity structure. Therefore, a dominant issue for accurate data assimilation is to determine the optimal (including cost) combination of satellite in situ data.

Now, the really difficult part of the requirements for in situ data is that the fields must be snapshots on scales that resolve the major features, i.e., eddies and fronts. The snapshots are necessary because the features evolve over time; they are generated, propagate, and decay. In the jargon of oceanography and meteorology, the data must be collected in a synoptic manner.

Until now, this synopticity has been almost impossible to accomplish. The analogy with weather data serves as a useful comparison. For the weather, realistic predictions can be made worldwide only because of the availability of modern data assimilation schemes that use 3-D synoptic observations. The models exhibit increasing skill for 3-5 days into the future, a timescale that is equivalent to about 1 or 2 months in the ocean.

The appropriate weather observations have been available only because of decades of intensive work in the development of instruments and data-reporting stations all around the globe. These data now are available from all airports, ships, aircraft, buoys, satellites, and other centers of high activity. In short, there is an expensive but fully operational reporting system that provides the data for assimilation into the weather prediction models.

Returning to the ocean, it is clear that such a reporting network is not available (it likely will not be available). The reporting period is relaxed because of the slower time scales in the ocean. Weather updates are necessary only weekly instead of several per day. However, there is a very serious setback in the change in scales between the atmosphere and the ocean.

The relative spatial scales of the synoptic features in the ocean are much smaller than in the atmosphere. The eddies are order 100 km in extent rather than 1,000 km; therefore, there are more of them in a region of given size. Full resolution of these features requires a significantly higher spatial density of data points. This data density issue makes a global reporting network a formidable task in the future.

The only near-term solution is to model only a fraction of the world ocean at a time, and research groups at many institutions worldwide are developing such regional models. (A second reason for the regional constraint is the speed and capacity of the fastest current computer technology.) Models with various levels of sophistication are being constructed, tested, and put into operation. A short list of examples includes the Mediterranean Sea, the Norwegian/Greenland Sea, the Antarctic Circumpolar Current, the Gulf of Mexico, and the Gulf Stream region. The data requirements even for these regional models are a formidable challenge for contemporary ocean measurement technology.

## OCEAN MEASUREMENT TECHNOLOGY

There are four methods for obtaining this type of data:

1. Satellite data, including images of surface temperature
2. Aircraft-launched temperature profile probes (AXBT) and water velocity profile probes (AXCP)
3. Ship surveys
4. Autonomous underwater vehicle (AUV) surveys (future).

As mentioned previously, the utility of satellite data involves developing and testing algorithms of their own. The aircraft provides a valuable capability, and also has been used for many isolated experiments including model tests. The time-honored research vessel is the slowest because of the relatively slow underway speed and the amount of time that is spent lying-to-on-station. Nevertheless, this remains one of the most reliable sources of data.

Typical modern shipborne instruments for this purpose include the conductivity-temperature-depth (CTD) profiles and the acoustic Doppler current profiler (ADCP). The CTD provides direct, accurate estimates of water sound velocity and density, and the velocity profiler provides a continuous measurement of water velocity. These are quantities of direct interest; any subset must rely on models of their own to estimate the full density and velocity fields.

The time-honored method of obtaining these data involves a serious compromise. The technique is to measure vertical profiles of density and sound velocity at widely spaced stations by deploying and profiling a CTD while lying-to. Then, to get underway at best speed and survey the region between stations by using much less accurate expendable temperature probes (XBTs). These are dropped from the ship while underway. The XBTs provide only a vertical profile of temperature, so the full 3-D sound velocity and density fields must be estimated by one of several additional assimilation algorithms. Finally, the total 2- or 3-D synoptic sound velocity field is calculated from this data set. Until very recently, water velocity, which is important for modeling in its own right, was obtained from the density field by assuming that the motions are quasigeostrophic.

*This surveying method is not really synoptic since it is so slow. The mesoscale features are changing as they are being measured, and the slowness of the measurement technique mixes up space and time. The remainder of this report discusses technological developments that have improved this situation—particularly two that are being actively pursued in the U.K.*

## NEW TECHNOLOGIES FOR OCEAN MEASUREMENT

In the last decade or so, new technologies have advanced the state of the art in this area. One serious contender is satellite-derived data products that include surface temperature, winds, and topography. This is ideal because satellites can cover an enormous area of the ocean very rapidly. On the other hand, the methods do not directly provide information on the ocean interior; they are developmental. Consequently, they require in situ oceanographic data for verification.

For in-situ measurements from ships, underway profiling of both water density (and sound velocity) and water velocity is now made as a matter of course. The density measurements are made by using a CTD, but it now is housed in a unique way.

One development in its present form, called the SeaSoar, is to install the CTD in a towed package with controllable lift that can be profiled from the surface down to about 500 m from a research vessel while it is underway at full speed. Simultaneously, the water velocity measurements are made by an ADCP that measures the speed of the water past the ship in many range (depth) bins below the keel. These instruments do not require the ship to stop, except to launch and retrieve the towed "fish" for very occasional servicing.

The less-developed second technique is to use an autonomous underwater vehicle that houses the CTD. In the future, this vehicle will be able to measure without an operator.

## THE SEASOAR

The SeaSoar is a towed vehicle that is available commercially from Chelsea Instruments Ltd., a small company located in East Molesey, near Hampton Court west of London. The SeaSoar has wings that are commanded to rotate to provide the depressing force for diving. The vehicle is flown with the wings alternately up and down to provide vertical cross sections in density. The ship runs multiple parallel lines to assemble the 3-D field. This up-and-down operating mode of the towed fish has often been called a tow-yo (short for towed yo-yo).

This device is a spinoff of the batfish, which was originally developed by Gould Ltd., in Canada some years ago. The batfish was further developed at the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL) in Wormley, England. The original developers at IOSDL were Vince Lawford (engineer) and Raymond Pollard (scientist). The technology has been licensed to Chelsea Instruments who, along with IOSDL, have developed it to the present state.

Models of the SeaSoar have subsequently been purchased from Chelsea by about 10 research organizations, including the Naval Research Laboratory and the Woods Hole Oceanographic Institute. These units have had several "teething" problems and do not have a strong reputation for their ruggedness. They have exhibited a tendency to leak through the oil gland. The underwater electrical connectors are badly located and break easily.

Also, the fish has a tendency to hang up when in the ship wake and not respond to the dive command. The control system is rudimentary, and there is little detailed understanding of how the fish responds to control inputs. An associated problem has sometimes occurred with the cable faring since it has not

been readily and cheaply available. Hence at high speeds, SeaSoar has occasionally been accused of causing kiting to the side.

As with many engineering developments, it was introduced long before its utility was recognized by more than a few researchers. Use has grown over time, with little strategic planning. In addition, since the commercial market has been small, various fixes of problems, upgrades, and documentation have not been generally available. As a result, some of the units have fallen into disuse.

### ACOUSTIC DOPPLER CURRENT PROFILER

The ADCP has enjoyed a more active developmental period by several manufacturers and researchers. Several models have steadily advanced from analog to digital controls and processing, to a wide choice of operating frequencies and multiple deployment options. Now there are hundreds of units around the world. Until recently, the acoustic components have been incoherent in the sense that they transmit a short, narrow bandwidth pulse, and the Doppler frequency of the reverberation is tracked as a function of time. Multiple beams are projected at angles  $30^\circ$  from the vertical. The Doppler frequency in the return from oppositely projected beams are differentiated in each time delay bin to provide an estimate of the horizontal velocity at depths below the ship. A coherent version of the ADCP, using a frequency-coded pulse, is being developed and tested by RD Instruments, San Diego, California, but other incoherent systems are manufactured by the Proudman Oceanographic Laboratory (U.K.), and Hydtec AB (Sweden). Remtech and Mors (France) is also developing one.

The ADCP development also has not been without trials. Although many units are in the field, there are few major component suppliers. The software has not been particularly user-friendly. It is often difficult to use older data because of the many changes in data acquisition software and poor documentation. Little is known about the accuracy with which the acoustic scatterers follow the water motion. The systems require reasonably sophisticated data reduction to eliminate biases in the inferred currents caused by navigating and pointing errors. Because these errors cause biases that are proportional to ship speed (the actual water speed typically is only a small fraction of the ship speed), the errors can overwhelm the signal. Finally, there is serious degradation of the data whenever there is significant ship motion in a seaway.

### AUTONOMOUS UNDERWATER VEHICLES

The U.K. has two new developments in autonomous underwater vehicles (AUV). The AUTOSUB Project is funded by the Natural Environment Research Council as a community research project; it is led by Peter Collar of IOSDL. The AUTOSUB supports two separate survey applications. The first is the multidimensional survey mode of using the yo-yo mode of operation to collect physical, chemical, and biological data. It is called DOLPHIN (deep-ocean long-path hydrographic instrument). The second application is for near-bottom runs on a grid for high-resolution geological/geophysical surveys.

The AUTOSUB development is in the second of four phases. Phase I was a multi-institution feasibility study of the major subsystems. The result is a conceptual design of DOLPHIN that is 6-m long and 1.2-m in diameter; it has a low-drag shape with contrarotating propellers. The hydrodynamic target is a volumetric drag coefficient of 0.014. The required battery supply (perhaps lithium sulphur dioxide) will take up much of the available volume. Important subsystem issues are

- Hull (material and shape)
- Control surfaces, trim, and buoyancy control
- Software
- Power supply and propulser.

The technologically interesting requirement here is the need to operate rapidly over the whole range of water depths without using much energy to control buoyancy. Phase II is for actual development of a range of subsystem technologies, including subsystem demonstrators. This is where the project is now.

Phase III is to construct a demonstrator vehicle which, at present, is expected to be a half-scale model using some less risky subsystems. Designing this demonstrator vehicle is clearly a balancing act between minimizing risk and demonstrating some new technologies in the field. Within projected funding, first deployment of the demonstrator should occur sometime in 1995. The full system will be deployed several years later.

The second development is an industry-independent R&D program with approximately 50-percent funding from the Department of Trade and Industry. The industrial consortium is composed of Marconi Underwater Systems, Moog Controls, and Chelsea Instruments. The development cycle is to be much shorter. The test vehicle depends much more heavily on available components (a 21-inch torpedo hull, available batteries for power, new dc motor, and new sensor and data acquisition system).

Tests of the vehicle have been initiated, as planned, in May 1992 on a tether in a reservoir in the U.K. The control functions now have been exercised successfully, and the tests will continue intermittently until the vehicle is shipped for the sea tests next winter.

The first scientific use of the vehicle is expected to occur in March 1993 in excursions under Arctic ice in the Greenland Sea.

The AUV developments are especially interesting because they are driven by the requirement for large-area oceanographic data collection. These are only two of several instrumentation developments for ocean sensing that have begun in the last decade. Others are the EPAULARD vehicle by IFREMER (France), the multinational ARUS vehicle under the European Community EUREKA program, the ARCS (Canada), and the earlier SPURV vehicles at the University of Washington Applied Physics Laboratory. It will be interesting to see how this one progresses in the next year or two.

## THE FUTURE

Both the SeaSoar and ADCP shipboard systems have reached a certain level of acceptance in the oceanographic research community (the latter more than the former). However, in a real sense, they are still primarily used by researchers and not for routine survey operations. Only at the Rennell Centre in Southampton, U.K., in the hands of Raymond Pollard, has routine operation really been achieved. The basic techniques are well known, but they are still developmental and require a trained engineer and scientist to keep them in working order and maximize their utility.

Several oceanographic programs could benefit significantly from improvements in these systems. If further developments are successful, they could easily be implemented as routine survey systems by many organizations. The first serious step is to construct a performance model of the system. These models must be developed and validated with test data so informed choices can be made about performance upgrades.

As an example for discussion, we choose the dynamic performance of both the SeaSoar and ADCP systems. Regarding SeaSoar, the vehicle responds in an unknown way to control inputs to the settings of the wings. A dynamic model that includes hydrodynamic lifting forces will enable an informed solution of the dead band in the ship's wake and enable other improvements in the design. An initial effort has been made along these lines in thesis work

performed at FWG, Kiel, the Federal Republic of Germany. An improved control system based on test results was designed and constructed; it is now commercially available. These results have not been widely distributed in the oceanographic community. A generally accepted dynamic model of the system does not exist. A serious effort for developing and testing such a model is recommended.

Regarding the ADCP, a model of the system that includes effects of ship motion would enable the construction of an algorithm to minimize motion contamination of the data. The algorithm would operate on a combination of data from the ADCP and a motion-measurement package to compensate for the motion. This type of algorithm has been very effective in removing motion contamination in other oceanographic systems such as buoys and towed temperature arrays. In addition, a model of the scattering process, including parameters of the acoustic signal and the distribution of biological scatterers, would provide guidance in system parameter choices and enable a more informed choice of operating modes.

The benefits of these instruments are being realized in both the U.S. and overseas countries. The time has come to construct performance models, validate them with engineering tests, and improve the systems. Only then will the community benefit from markedly more reliable instrumentation that works at higher ship speeds. This in turn will lead to higher quality data as a result of both improved inherent accuracy and improved synopticity. There would then be a path for collecting data of high utility for model developing and testing.

Development of oceanographic AUVs is advancing rapidly, and only time and continued funding at serious levels will tell how useful the technology will be to the oceanographic, and in particular, the ocean modeling community. If successful, they offer the advantage of reduced ship-operating costs. On the other hand, there is much risk in banking on this new and untried method of obtaining oceanographic data. Furthermore, the AUV is not expected to make research vessels outdated.

## CONCLUSIONS

Several interesting developments in instrumentation technology in the U.K. could revolutionize the way that oceanographic data are routinely collected. Successfully developing these tools will improve the capability of the oceanographic modeler to develop and validate oceanographic prediction models.

## THE EMBASSIES: TECHNOLOGY ROUNDUP

### FRANCE

*For more information on French items, contact Dr. Michael Michaud, Science Counselor, American Embassy, Paris, USOECD/SCI, APO NY 09777; International: 19 Rue de Tranqueville, 75016 Paris; Tel: +33 (1) 45-24-74-31; Fax: +33 (1) 45-24-74-80.*

#### French Government Launches Programs in Biotechnology

French Research and Technology Minister Hubert Curien announced the launching of a new biotechnological program—Bioavenir. He also announced that the new project will be submitted at the European level when it is France's turn to preside over the EUREKA Program.

Bioavenir is a 5-year program that will involve up to 500 researchers with a total budget of \$303.8 million, including a government contribution of \$116.1 million. Two thirds of the government's share will come from the Ministry of Research and one third from the Ministry of Industry. The remainder will be funded by Rhone-Poulenc.

According to the French government, the potential world market for the products covered by Bioavenir could reach \$56.6 million annually by 1995. The challenge is a scientific as well as an economic one. Bioavenir's strategy, which aims at modifying research methods on biomolecules, will focus on three sectors:

- Health - atherosclerosis, cancer, and age-related diseases
- Agriculture - plant varieties capable of resisting attacks by pests; pesticides that are better targeted, active in small doses, and not toxic for humans and the environment
- Chemistry - enzyme catalysis and research on industrial microorganisms.

Quoted by the daily *LeMonde*, Philippe Desmarescaux, who supervises research in the group, indicated that "The program is not rigid and no rigorous distribution among the three sectors has yet been decided with respect to financial resources. We will not hesitate to rapidly open the new partnerships. Roussel-UCLAF, the French subsidiary of the German corporation Hoechst, has reportedly already announced that it will most likely participate in cer-

tain Bioavenir projects, but without going into details." *LeMonde* emphasizes that the partnership will, in any case, concern research with no industrial repercussions, for obvious reasons of competitiveness. However, the desire of both corporations to join efforts on certain aspects of the program is evidence, according to *LeMonde*, that they want to keep up with their American and Japanese competitors.

### ITALY

*For more information on Italian items, contact Mr. Reno Hamish Ili; Office of the Science Counselor, American Embassy, Rome, APO NY 09794-9500; International: Via Veneto 119/A, 00187 Rome; Tel: +39 (6) 46741 (Ext. 2375); Fax: 39 (6) 4674-2356.*

#### BIOMEDICAL ROUNDUP FOR ITALY

##### Italian National Center for New Materials

In December 1991, I called on Paolo Cavaliere, Director of the National Center for Research and Development of Materials (CNRSM). The center is located in Mesagne, Puglia (i.e., near Brindisi on the heel of the Italian boot). The purpose was to get a first-hand impression of the new Italian effort to found science parks in the south similar to the successful Bari Technopolis. In passing, however, I gained insight into a broad-based advanced materials program of the Italian government that is delving into composites, microelectronics, advanced ceramics, and biomaterials.

Cavaliere noted that CNRSM is just one part of a Cittadella Della Ricerca (City of Research) that is being constructed north of Mesagne. Several divisions of CNRSM will begin operations at the Cittadella in early 1992. The idea is eventually to create a center of excellence for strategic materials technology in Italy—perhaps even in Europe. Its presence in Puglia takes advantage of the nearby steel industry at Taranto and the universities of Lecce and Bari and reflects the Italian goal of developing Southern Italy. Both goals (materials research centralization and southern development) will be achieved by having first-class equipment on-site for microstructural and microanalytic characterization.

The CNRSM is a joint share company with 14 shareholders, including universities and local governments. However, five shareholders are responsible for 85 percent of the subscription: the Council of

National Research (CNR); the Innovation, Environment, and Alternative Energy Agency (ENEA); Finpuglia (a regional finance agency); SPI (a company of the IRI Group); and CISE (a research entity of ENEL). The CNRSM has five divisions:

- Division I prepares new or improved materials and defines new technological processes;
- Division II develops unconventional treatment techniques and innovative methods for analysis of surfaces;
- Division III does microstructural and micro-analytic analysis with X-ray and electron beams;
- Division IV characterizes the macroscopic properties of materials to optimize preparation processes; and
- Division V synthesizes, prepares, and evaluates biomaterials for clinical purposes and prepares and characterizes finished products. According to Cavaliere, this division will do everything from carbonium fibers to composite polymers. In conjunction with two Italian companies, Sorin and Fidia, it is developing biocompatible parts for the heart.

The director of Division II (Surfaces) told me that his team will continue work that was begun at other sites around the country, e.g., the University of Padua. The difference at Mesagne (for him) is that he has a laboratory that was specifically designed for surface analysis scientists. He can do electron spectroscopy for chemical analysis and secondary ion mass nuclear techniques. The director of Division V (biomaterials) spoke about his work with intelligent structures and systems. He designs molecules using mathematical models, particularly in polyparaffin and polymer gels. Division III's project for European advanced materials analysis will be a major task of CNRSM and will take advantage of the 400-KeV analytical transmission electron microscope.

Throughout the visit, Cavaliere and his colleagues seemed proud of their equipment (some was still crated at the site). The CNRSM will be supported by a 300-KV ion implanter, MOCVD reactors for plasma, a 3-MV tandem electron accelerator, ESCA, a scanning auger microscope, and SIMS. According to Cavaliere, this will be the only site in Europe with such an advanced collection of equipment.

At least 16 other entities will be located on the Cittadella site. I visited the former hospital building where Fiat BPD will conduct carbon fiber research. Internova is developing metallic matrix composite

structures with aluminum and titanium alloy and ceramic matrices. Another firm, Ecoplast, will conduct research into new plastic materials and into new techniques for recycling plastic waste.

Cavaliere is interested in attracting collaboration with U.S. public, university, and private entities. He noted ongoing cooperation with Daimler-Benz and the University of Marseilles in ceramic materials as well as with IBM and Philips of Holland in developing a third-generation electron microscope. He also noted recent cooperative agreements with the former Soviet Academy of Science and with the Peoples Republic of China. In Cavaliere's opinion, Europe has lagged behind in new materials research; the U.S. has the best research in this area. He would like to co-host a seminar with an American institution to bring together public and private laboratories from both countries to see how they might cooperate. France had conducted such a seminar, and it had sparked several bilateral science projects. He would also be interested in having a U.S. university collaborate either with teachers or students, in the masters degree course that will be offered at the Cittadella. France and Italy are planning a new materials seminar for 1992 under the bilateral science cooperation agreement. Perhaps the CNRSM could participate in this effort.

## **Milan Laboratory for Computerized Bone Reconstruction**

### **Introduction**

In Milan, several entities are cooperating to create a Laboratory for Management of Imaging and Robot Utilization in Surgery (MIRUS), which is considered to be the most advanced laboratory of this type in Europe. The Laboratory of Robotics and the Biomaterials Center of Milan at Polytechnic and the Division of Plastic and Reconstructive Surgery at Niguarda Hospital are participating. Several Milanese industries are providing financial support. The technicians at MIRUS will be able to reconstruct the original shape of fractured bones through tridimensional images obtained by a computer. Thus, the artificial bone will have a complete resemblance to the original one.

### **Animals Genes Inserted in Vegetable Cells**

Groups of researchers in the U.S., the Federal Republic of Germany, France, and Spain want to develop a method for transferring animal genes into plants to utilize the more advanced immune system

of the animals. Italy is advancing significantly in this type of research. A National Agency for New Technology, Energy, and Environment team at the Laboratory of Genetic Engineering has injected a vegetable pathogenic agent into mice to induce the production of antibodies in the small mammals. These antibodies are biotechnologically treated for their transfer to the plant so that once injected into the plant, they reproduce and make the plant immune to the specific pathogenic agent under test. The team is experimenting on a virus of the artichoke; they were able to produce artichoke plants that were immune to the virus being tested by using this technique. The aim is to verify whether the acquired immunity of the plant is resistant, reproducible, and stable in time. Achieving this goal will be valuable, both environmentally and economically. The method could rid the environment of pesticides and antiparasite substances. There could be savings on chemicals and mechanical and human work. According to Dr. Eugenio Benvenuto, head of the laboratory, the Italian team seems to be well advanced in this research. They may achieve their goal in 2 or 3 years.

#### **Activity of the Trieste International Center for Genetic Engineering and Biotechnology**

The Trieste International Center for Genetic Engineering and Biotechnology (ICGEB) was created in 1983. It is conducting advanced research for prevention of tumors through biotechnology techniques in the food sector. In the case of tumors, the ICGEB research laboratory has isolated the human papillomavirus (HPV), which is considered to be responsible for tumors of the uterus. Research is now centered on finding a vaccine or a drug through genetic manipulation that might be able to combat the HPV activity. In the food area, the ICGEB has extracted from the phanerochaete chrysosporium mushroom two enzymes that can metabolize wood and cellulose. Thus, two components of the vegetable world become biodegradable. These two components were previously unassailable by enzymes contained in the digestive track of mammals—including man. The bioreproduction of these enzymes will open the way to transforming wood and cellulose into sugars, thereby, making two substances available as food that were considered inedible. The ICGEB is expected to spend about \$56 million in research for the 5-year period 1989-94; 45 percent of this is expected to be made available by the Italian government.

The ICGEB is interested in increased support from official U.S. sources. Several U.S. scientists

participate in the direction of and research done by this center.

#### **Bari—A Model for Science Parks**

In January 1992, Italy's Ministers of Research (Ruberti), Budget (Pomicino) and Southern Development (Mannino) signed a set of final regulations to implement a plan for establishing science parks in Messogiorno, southern Italy. The accord unblocks nearly \$1 billion for the period 1990-92, half of which Ruberti will control. The regulations spell out how and when proposed southern science parks can apply for funding.

The purpose of the parks is to spur development and competitiveness of the south by encouraging the collocation of research, innovation, and industry. Ruberti thinks that the shortage of funds relative to demands will force a rigid selection process. The model against which applicants will be judged is the "tecnopolis" near Bari in the Province of Apulia, the heel of Italy's boot. According to the Ruberti, the applicants will need to show that they can attract new industrial research laboratories and provide them with real high-technology services. He wants funds to go to applicants that have a strong tradition of research and a significant presence of industrial firms.

When I visited Bari Technopolis, it was clear why Ruberti would like new science parks to exhibit the same business-like approach to innovation. Director General Umberto Bozzo said that science parks should not be seen as a new method to channel funds to the universities. Also, planning for new parks should not revolve around the purchase of buildings and equipment. Bozzo sees two key ingredients if Bari's success as an innovation center and catalyst for economic and social development is to be replicated. First, science parks must have trained personnel who can provide real support to research and innovation. Second, the parks must focus on contacts with firms in northern Italy and other parts of the world and find ways to satisfy their needs.

Launched in 1984-85, the management consortium of Tecnopolis Csata Novus Ortus (Tecnopolis) seems to have evolved a system that it can export to other parks. Tecnopolis was a founding member of the International Association of Science Parks and apparently maintains good contacts on four continents through a market-access consortium called Trimac. When the European Community recently chose 100 experts to advise member countries on establishing parks, six were picked from the staff of Tecnopolis. Bozzo said that Bari is currently

providing consultant services to science parks in Ireland and Spain. They are also consulting for the management of the regional science park in Sardinia, backed by physicist Carlo Rubbia.

Tecnopolis is a nonprofit consortium shared by universities, public laboratories, and private companies. In the beginning, Tecnopolis emphasized informatics and so maintains a computing center with communication and research laboratories for CAD/CAM, CAI/CAL, robotics, artificial intelligence, microelectronics, and optoelectronics. It tries to stimulate economic development in southern Italy. The 250 employees work in 45,000 square meters of office space on a 35-hectare site provided by the University of Bari. The park boasts a business incubation program working with 74 local enterprises; 6 are in a start-up phase. It houses the School for Advanced Studies in Industrial and Applied Mathematics and the Advanced School for Managing Innovation and Technology. The park is served by a 100-megabit optical fiber local area network, connected to a 34-megabit optical bigger metropolitan area network and finally to the 2-megabit National Research Network (GARR).

In the attempt to create a tecnopolitan district, Tecnopolis encourages large companies to establish a laboratory in the park and then helps them to move off into nearby industrial sites. Four large firms, including Olivetti and Telettra, moved to the park then out into the southern Italian economy. Another 10 major companies, including Laben (electronics and software engineering for space applications), have located research activity in the park. Fiar and Tecnospazio (research for original applications of artificial intelligence and advanced robotics) also located there.

The presence of adequate funding and a strong model will not necessarily guarantee the smooth launch of several science parks in the Italian Mezzogiorno. A previous generation of Italians attempted to accelerate economic development in the south by establishing heavy industry there. These examples are now popularly called cathedrals in the desert. Italy already has a shortage of engineers and scientists. The best might not want to migrate from secure laboratories in the north to experimental ventures in the south. Nevertheless, to the extent that new parks imitate Tecnopolis, they should increase their chances of a successful launch.

## SPAIN

*For more information on Spanish items, contact Mr. Robert G. Morris, Science Counselor, American*

*Embassy, Madrid, APO NY 09285-8500; Tel: +34-1-577-4000; Fax: +34-1-577-5735.*

## Spain's International Cooperation in Science and Technology

### Introduction

Cooperation with the U.S. is excluded from this report since information on agreements with the U.S. government and U.S. government agencies is available in the annual science, technology, and American diplomacy reports (Title V Reports). A government-government science and technology (S&T) agreement with the U.S. no longer exists. An agreement in force from 1975 through 1989 under the defense cooperation agreement expired by mutual agreement. Although both parties want a separate follow-on agreement for S&T cooperation, its negotiation has been delayed by discussions of terms for protection of intellectual property rights. This agreement largely pioneered S&T cooperation in Spain. When Spain joined the European Community (EC) in 1986, it redirected its S&T focus. Spanish sentiment now exists for balancing this European orientation with a return to officially sponsored transatlantic cooperation.

### Bilateral Cooperation

Spain has bilateral S&T cooperation agreements with at least 20 countries. A most active one is with the Federal Republic of Germany (FRG), which has subagreements covering energy, atmospheric sciences, astronomy and astrophysics, water purification, aerospace, microelectronics, materials, and agriculture. Bilateral arrangements with other EC countries augment Spain's participation in EC multilateral programs. Cooperative agreements with Eastern Europe and Latin America bolster Spain's political as well as economic policies.

**EC Countries.** Spain's cooperation with EC member countries is mainly through EC-wide programs like the Framework program. Still, a web of cooperation with these countries exists separately and predates Spain's EC entry. For example, bilateral cooperation with the FRG dates from 1970. In the early 1980s, Spain and Portugal began integrated actions or joint programs between cooperating laboratories. By 1987, these action programs had been extended to include France, Italy, the FRG, and the U.K.

Since the early 1980s, bilateral exchange programs have also traded scientists with EC countries,

mainly France and the U.K. More modest programs have involved the FRG, Portugal, Italy, the Netherlands, Italy, Denmark, and Belgium. In addition, Spain has bilateral cooperation agreements with the FRG, Italy, France, Greece, the U.K., and Portugal.

**Eastern Europe.** All agreements have 5-year terms, extendable for 5 years more (except for Bulgaria, with 1-year extensions); all provide for meetings of a joint commission, usually every 2 years. With Bulgaria, the joint commission is under the 1971 economic cooperation agreement. The agreement with the former Soviet Union created a secretariat to run the program. Program specificity is broad, with the usual provision for exchanges as well as joint projects in areas fashionable at the time the agreement was signed. [Cooperation will presumably continue with Russia, as the Soviet Union's main S&T successor, and as the agreement with the former German Democratic Republic (GDR) folds into the agreement with FRG.]

In 1990, Spain spent about \$400,000 on bilateral cooperation with Eastern Europe. About 225 research scientists went to Spain from Eastern Europe and 90 left Spain. The following Eastern European countries have cooperation agreements with Spain:

- Yugoslavia (since 1974)
- U.S.S.R. (1979-separate agreement on environment in 1991)
- Hungary (1979)
- Poland (1979)
- Bulgaria (1980)
- Czechoslovakia (1980)
- former GDR (1984).

**Latin America.** A modest S&T cooperation program with Latin American countries fosters goodwill while enabling Spain to take advantage of certain areas of research excellence there.

A 1985 agreement with the Peoples Republic of China (PRC) is fairly active and visible. There is a joint commission to oversee some 40 projects now involving annual exchanges of 16 to Spain and 10 to the PRC. The 1991 agreement with Israel is the most recent and reflects steadily improving relations between the two countries, as exemplified by President Gonzalez's December 1991 visit to Israel (first ever by a Spanish head of government).

Agency-to-agency agreements between the Spanish National Research Council (CSIC) and foreign counterparts complement these intergovernmental accords.

Table 1 lists international agreements of the Spanish National Research Council (CSIC).

The first operational arm of the Western European Union will be a satellite ground station installed in Madrid in 1992. Initial investment is \$16 million, of which Spain will contribute \$4.5 million. The initial staff of 30 could grow to 300 after 1994, with an increased budget. Spain gained much of the expertise that enabled it to attract such a facility by operating since 1964 at Robledo one of the three NASA deep space tracking stations. The Robledo undertaking also contributed to Spain's selection several years ago as the site of an ESA ground station.

## EC Programs

Definitions and comments that apply to this section on EC programs are in Table 2. The programs are defined in Table 3.

## Few Students are Studying Engineering

The proportion of Spanish students in engineering and technology is the lowest of any European Community (EC) country. On the other hand, a higher percentage of Spaniards are studying social and economic science and law. These figures were released by the Ministry of Education and Science as it prepares its university program for the remainder of this decade. The percentages for engineering and technology students are

Spain	16
Greece, Ireland, Italy, Portugal	19
Remainder of the EC	20

In exact and natural sciences, Spain's proportion is about equal to the EC average (11 percent), as is the percentage pursuing the humanities (17 percent). The relative number of university students in Spain is comparable to that in the more developed EC countries. The ministry notes EC statistics showing that by the end of the decade, Spain will have a greater proportional demand for qualified workers (including graduate engineers) of any country in Europe.

## Almeria Solar Energy Project Is Partially Eclipsed

A \$63-million solar energy project jointly supported by Spanish, U.S., Israeli, and German groups is shut down because of the bankruptcy of Luz (a joint U.S.-Israeli company) and because of German science and technology (S&T) budget cuts. German participants were the firm Testsol and the DLR Federal Center for Aerospace Research. For

Table 1. International Agreements of CSIC

<b>Austria</b>	Academy of Sciences
<b>Belgium</b>	Catholic University of Louvain
<b>Brazil</b>	National Council of Scientific and Technological Development (CNPQ)
<b>Bulgaria</b>	Academy of Sciences
<b>Chile</b>	National Scientific and Technological Research Commission (CONICYT)
	University of Chile
	University of Santiago de Chile
<b>PRC</b>	Academy of Sciences
<b>Cuba</b>	State Committee for Economic Collaboration
<b>Czechoslovakia</b>	Academy of Sciences
<b>Egypt</b>	Academy of Scientific and Technology Research
<b>France</b>	National Center for Scientific Research (CNRS)
	National Institute of Health and Medical Research (INSERM)
<b>FRG</b>	German Academic Exchange Service (DAADF)
	German Research Society (DGF)
	Max Planck Society (MPG)
<b>Hungary</b>	Academy of Sciences
<b>Israel</b>	Weizmann Institute
	Hebrew University of Jerusalem
	University of Tel-Aviv
<b>Italy</b>	National Research Council (CNBR)
<b>Mexico</b>	National Council of Scientific and Technological Research (CONACYT)
<b>Morocco</b>	National Center for Coordination and Planning Scientific and Technological Research
	Cadi Ayyad University of Marrakesh
<b>the Netherlands</b>	State University of Utrecht
<b>Poland</b>	Academy of Sciences
<b>Portugal</b>	National Institute of Scientific Research (NIC)
	National Board of Scientific and Technological Research
<b>Switzerland</b>	University of Zurich
	Swiss Federal Institute of Technology (ETH), Zurich
<b>U.S.S.R.</b>	Academy of Sciences of the USSR (temporarily suspended)
<b>U.K.</b>	The British Academy
	The Royal Society
	The British Council
	The Ramsay Memorial Fellowships Trust

Table 2. Definitions and Comments on EC Programs

<b>Program:</b>	EC Program such as the Framework program, or subprogram, usually a part of the Framework program, such as ESPRIT
<b>Term:</b>	Period for which the program planned; may be separated into phases, which may overlap. Budget approved for the term. May not all be spent during the term (or phase). Surplus usually carried over into next period. For programs like ESPRIT, participating industrial institutions may be expected to contribute additional funds.
<b>Projects:</b>	Number of S&T efforts under the program actually begun; may not all be completed.
<b>Spanish Projects:</b>	Number in which Spanish entities participate whether or not they lead them. Latest data are given, often through 1990, but may lag behind data for overall program.
<b>Spanish Contribution:</b>	Usually planned, initial, or to date, not for the life of the program or program phase. Comprehensive data have just been published covering the period through 1990. Percent contribution refers to Spain's payment share to the EC for the programs as known, not necessarily for the entire budget of the program. Spanish analysts are not always clear on this point.
<b>Spanish Return:</b>	Usually for a period less than the life of the program, often unspecified. Analysts in Spain may be optimistic and contradictory in reporting these data. Percent return means percent of the accounted expenditures that have come back to participants in Spanish projects. Thus if the contribution and return are the same percentage (for the same accounted time), Spain is getting all its money back.
<b>Exchange Rates:</b>	Nominal dollar figures obtained on basis 100 pesetas = \$1; \$1.3 = 1 European Currency Unit (ECU).

Table 3. Program Definitions

<b>BRIDGE</b>	R&D program in biotechnology of the EC
<b>BRITE</b>	Basic Research in Industrial Technology for Europe
<b>ECLAIR</b>	European Collaborative Linkage of Agriculture and Industry through Research
<b>ESPRIT</b>	European Strategic Program for Research and Development in Information Technologies
<b>EUREKA</b>	European Research Coordinating Agency (EC members, commission plus seven other European countries)
<b>RACE</b>	R&D in advanced communication technologies in Europe.

decades, solar research has taken advantage of Almeria's sunny skies on the southern coast of the country. Spanish and German firms are investigating whether they should resume the work of Luz. Meanwhile, even Spain has cut back its contribution.

Firms from Spain, the Federal Republic of Germany (FRG), the U.S., and Switzerland were also participants in project Phoebus to build a 30-MW solar power facility in Jordan. Phoebus is a \$180-million casualty of the Gulf War. (Bonn has reported on the 1-MW plant at Toledo that will be constructed by the FRG's RWE-Energie and Spain's Fenosa.)

One hand takes away and the other one gives. A group from Madrid, Louvain, Dublin, and London proposes to use Almeria's solar oven in high-temperature studies of metals. Spanish workers with seed funds of \$150,000 hope to qualify for an EC grant of \$2.8 million by the end of 1992. The idea of the experiments is to substitute the solar oven for a laser. Test lasers take 15 kW and cost \$300,000. The oven has greater initial cost but little operating cost; it can test larger samples with operating temperatures of 800-1200°C.

#### Minister's Visit Assures Antarctic Research

In 1988, Spanish scientists began working at their own Juan Carlos I Base on Livingston Island in the South Shetland Islands. In 1991, Spanish Antarctic research received two boosts—the launch of its new \$90-million polar research vessel *Hesperides*, and the Marathon Antarctic Treaty Conference that led in October to the protocol of Madrid on environment and minerals exploitation. In December 1991, a third boost was received when Minister of Education and Science Javier Solana toured Antarctic research bases. The visit was important for the scientists; the minister controls much of the budget for Antarctic research. Upon his return, Solana pronounced the experience very positive, very interesting from every point of view—from the scientific side on the *Hesperides* and on the bases, and from a personal side to see how one lives in the hard conditions.

U.S. Antarctic hands will sympathize with Solana for the difficulties experienced when his departure from King George Island was delayed 2 days by weather. He and his group, which included the National Research and Development Plan's Luis Oro and MFA's Antarctic Officer Jose Luis Candela, were rescued by Argentine Armed Forces and flown to Punta Arenas, Chile. The Minister earmarked \$3.25 million for Antarctic research in 1992. Thus, the average Spaniard is much more aware of his

country's efforts in Antarctica than he was a year ago.

#### Expo 92 Will Become Technology Park

The 1992 World Exposition of Seville (Expo 92) will run from April until October on the Island of La Cartuja in the Guadalquivir River. After the quincentennial event, La Cartuja will be the site of Spain's newest technological or research park. Others are located at Madrid, Barcelona, Bilbao, Valencia, and Oviedo, and buildings are planned for Malaga, San Ciprian de Vinas (Galicia), Valladolid, and Tenerife (Canary Islands). The object of considerable political interest, the Seville park will come under national, regional, and city operation.

Seven institutes of the National Research Council (CSIC) will move from cramped or shared quarters elsewhere in Spain to form the nucleus. Prominent among these will be the Seville branch of the Materials Science Institute, now housed in four different buildings at the university. Other parts of S&T facilities of Seville University will also move to the island. Interest is keen, of course, in attracting industry to the park since ATT has set up in Madrid and Hewlett-Packard in Barcelona's park. There will be plenty of buildings for use.

A special effort is being made to get Expo exhibitors, like Siemens or Sony who have their own buildings, to retain them and convert them to research laboratories, although multinationals do most of their research and development (R&D) at headquarters. The head of Sony-Spain recently expressed doubt that his company would do so. He said he needed to better understand what kind of R&D could be done there, noting that Sony prefers to keep its research laboratories together with its factories so they can interact. He went on to say that what the scientists at Sony would need does not exist in Spain. The firm, he concluded, even had to train repair personnel in Spain and was thinking of opening a training school for that purpose. Seven or eight members of another Japanese group will be in Seville in early February to investigate post 1992 use of the Seville site.

#### UNITED KINGDOM

*For more information on British items, contact Mr. Jeffrey Lutz, Science Counselor, American Embassy, London, PSC 901 Box 38, FPO AE 09498-4038; International: 24 Grosvenor Square, London, W1A 1AE; Tel: +44-71-499-9000 (Ext. 2238); Fax: 44-71-409-1637.*

## U.K. ENVIRONMENTAL AND NEW MATERIALS RESEARCH GETS INCREASED SUPPORT

### England's Link Scheme is for Collaborative Research with Industry

The Science and Engineering Research Council (SERC) announced a medical implant program under the government's Link Scheme for collaborative research with industry. The United Kingdom's Link programs made their first award almost four years ago. The Link initiative provides a mechanism by which the public sector in the form of universities, research councils, and government departments join with private-sector companies to pursue agreed-upon research programs. The goal of the programs is to provide a link between the inventor and the manufacturer to promote the transfer of technology from the laboratory to the market place. While the majority of fields are likely to be in engineering, any exploitable technology is eligible for consideration.

The use of materials for implanting in the human body is rapidly increasing, but a significant fraction of implant surgery today is to replace existing, worn-out implants. This £10 million program, (Exchange Rate: £1 = \$1.75) jointly supported by government (SERC, Department of Trade and Industry/DTI, Department of Health and Medical Research Council) and industry, aims to provide second-generation medical implants with increased lifetimes. The use of novel materials in the body will be a key area of research, leading ultimately to the development of new products that will benefit the patient as well as British industry as the supplier. In particular support will be targeted on improved implant materials and fixing techniques, repair of bone fractures, vascular grafts, heart valves, dental implants, pacemakers, and other active implants.

SERC has agreed on joint support for 23 of the 28 Link programs to date, each lasting from 3 to 6 years. SERC has made available funding up to some £52 million. Program subject areas include topics in electronics and communications, measurement and sensors, materials, food and biosciences, and a range of engineering disciplines. There are now 150 active collaborative projects involving industry and higher education institutions, spread across these different program areas to which SERC is contributing £14 million. In addition, there are some 100 further projects that have been technically approved. The projects described below give an idea of the quality

and extent of the collaborations, and the interdisciplinary nature of the research.

**Industrial measurements systems.** The 6-year SERC/DTI program was launched in April 1988 and now has 23 projects under way. The program's coverage is broad, both in technologies used and application areas. It concentrates on instrumentation and measurement technologies where systems integration is emphasized. Acoustic signal processing technology can now be considered for industrial process monitoring in a wide range of applications. Such technology has particular significance in process monitoring in the hostile conditions found in chemical and nuclear plants. Mechanical noise can be generated as a result of fluid/wall friction or viscosity changes in moving liquids and is also influenced by solid material content. Imperial Chemical Industries (ICI), AEA Technology Sonomatics Ltd, and UMIST are collaborating in a £351,000 project to further this technology. It is hoped that this will result in its eventual application to a wide variety of processing plants.

**Optoelectronics.** This 5-year SERC/DTI program, announced in April 1989, focuses on research into the integration of optoelectronic devices and techniques within optical communication and information processing systems, including work on devices and enabling technologies. One recent project was developing high-power optical pumps to radically improve the performance of optical fiber amplifiers to permit more efficient and cheaper transmission of information through optical communication networks. Optical fiber amplifiers boost the light signal within the fiber without the requirement to convert the light into electrical signals, amplify it, and reconvert it to light. They are much less complex than conventional amplifiers, having only four components (the optical pump being one) and can be spliced directly into the fiber. Fiber amplifiers are seen by many as the key to future optical communication systems for both long-distance transmission through underwater cables, for example, and for short-distance systems, such as local area networks. This £2 million project aims to use novel techniques to develop high-power semiconductor laser pumps operations at the relevant wavelengths of 980 and 1490 nm. At present, practical laser sources are not available at these wavelengths. Such pump lasers must be reliable at very high output powers, with a 25-year life for use in underwater systems. Six partners are collaborating in this project: St. Andrews, Glasgow and Southampton Universities, BNR Europe (formerly STC Technology), Plessey Casswell, and MCP Wafer Technology.

## Advisory Council on Science and Technology Reviews U.K. Science and Technology Issues

The Advisory Council on Science and Technology (ACOST) is an independent council formed in 1987 to advise the government on science and technology (S&T) issues. The 19-member council is chaired by Sir Robin Nicholson, Executive Director of Pilkington PLC. The other members are the chairmen of the Advisory Board for the Research Councils (ABRC) and the Universities Funding Council (UFC), senior industrialists, and academics. According to its charter, ACOST advises the government on:

- Priorities for S&T in the U.K.
- Application of S&T, developed in the U.K. and elsewhere, for the benefit of both the public and private sectors in accordance with national needs
- Coordination in collaboration with departmental advisory bodies of S&T activities
- Nature and extent of U.K. participation in international collaboration in S&T.

The report, *Science and Technology Issues: A Review by ACOST*, examined British S&T issues, performance, and opportunities in the interlinked global, European, and British markets. It grew out of a 1990 House of Lords S&T committee recommendation that ACOST prepare periodic strategic reviews of public and private sector S&T issues. The ACOST will submit reviews about every 3 years.

To generate a competitive technology-based economy in the 1990s and early 21st century, the U.K. must develop

- a coherent framework of S&T goals, strategies, and policies,
- adequate and well-directed national investment in S&T activities,
- positive public attitudes toward S&T,
- a supportive regulatory regime,
- an effective system of education and training in S&T,
- a vigorous and excellent S&T research base,
- sufficient and effective industrial investment in research and development (R&D), exploitation of R&D, and innovation (more generally,
- an economic climate that encourages innovation, including sufficient economic stability, to enable the risks and rewards to be sensibly evaluated, and

- effective mechanisms to encourage technology transfer.

The ACOST identified several key weaknesses in U.K. S&T. It found that spending on R&D and innovation in industry may be too low and costs are rising faster than general inflation. The ACCOST judged there should be more stability in U.K. S&T policies, and departments should work more closely together when activities overlap. It urged much more debate about the role of the science base, its long-term contribution to the national economy, and the relative importance that should be attached to training, research, and exploitation....and for...consideration of...funding and priorities including whether the distribution of science base funding is well matched with national needs.

The U.K. lags in R&D and spends less than its main rivals. According to a study cited by ACOST, the top 100 U.K. companies spend only \$2,875 per employee on R&D while U.S. companies spend \$7,012 and those in the Federal Republic of Germany (FRG) spend \$8,121. Many U.K. companies also are insufficiently innovative. The ACOST speculated that the main reasons are:

- Higher real cost of capital faced by those investing in R&D and innovation compared, for example, with the FRG and Japan
- Insufficiently predictable U.K. economic environment and insufficiently stable government policies
- Inability of the U.K. education system to produce a workforce with adequate technological and innovative skill
- Lack of appreciation in industry for the contribution that technology can make to competitiveness, which is reflected in a similar undervaluing of scientists and technologists.

The ACOST noted the U.K. has only a 5-percent share in the fast-growing international R&D market. It identified four main target areas:

1. Energy supply, efficiency, and pollution control
2. Health, including HIV research
3. Global technology, companies, and competition
4. Third-world economic development and agriculture.

The ACOST criticized the government for taking a haphazard approach to international R&D

collaboration. It seldom initiated major collaborative programs and often has not gained the full industrial benefit from its contribution to those it does join. The ACOST recommended a more active governmental approach to international collaboration, including better analysis of long-term opportunities and strategic options and more willingness to commit resources to maximize benefits from collaboration. The ACOST agreed with the House of Lords S&T committee that too much of the U.K. science budget may be committed to international subscriptions that can fluctuate.

The ACOST concluded that as European Community (EC) economic integration accelerates issues (such as pollution control), harmonization of standards, competition policy, and industrial competitiveness will increasingly need to be tackled at a European level. The EC Framework Program already coordinates energy R&D and environmental and life sciences research.

The ACOST identified three U.K. market sectors that merit more attention: health and medicine, energy, and physical infrastructure. In medicine, the U.K. should develop expertise in in-vitro diagnostics where it holds just 3 percent of the \$8-billion market. In energy, the U.K. needs to spend more on renewable energy and energy-efficiency R&D, and the government will probably have to aid in developing cleaner and more efficient technology for burning coal. The British transportation and communication infrastructure needs to be updated. There are opportunities for computerized urban traffic control, linking fiber-optic telecommunications with railways, and remote monitoring of underground gas and pipelines. All of these areas have commercial applications for British companies in the international market.

#### **U.K. Environmental and New Materials Research Gets Increased Support**

At the December 1991 meeting, the Science and Engineering Research Council (SERC) agreed to increase support for environmental and new materials research. Commenting on the increase, SERC chairman Sir Mark Richmond said, "This welcome increase will enable us to support more research of high priority. Work of national and international importance, such as the development of new materials, clean technology, Earth observation, and atmospheric chemistry, will particularly benefit. Some additional funds will also be used to support research grants and postgraduate training in other areas."

Approved was a £1.6-million contribution to the building of a large wave basin facility for coastal engineering research at Hydraulics Research, Wallingford. The benefits of the facility will include improved techniques for coastal protection, more accurate prediction of sediment movement, and greater understanding of effluent behavior and dispersion. The interactions of sea and coastline are of interest and concern to British citizens. The SERC investment here has a potentially enormous gearing in its future payoff in the costs of protection measures.

The SERC also approved annual subscriptions for 1992 to four international bodies—the European Space Agency (ESA), the European Synchrotron Radiation Facility (ESRF), the Institute Laue-Langevin (ILL) and the European Science Foundation (ESF).

The director general of the British National Space Center (BNSC), Mr. Arthur Pryor, briefed SERC on the outcome of the November 1991 meeting of the ESA Ministerial Council. A highlight was the resolution to support advanced instruments for climate and environmental research on the polar platform satellite due for launch in 1998. The launch will have a major U.K. contribution. The SERC subscription to ESA for 1992 of up to £27 million was approved.

Construction of the ESRF in Grenoble began in 1989; it is now 6 months ahead of schedule. Operation of the first seven instruments is scheduled for September 1994, but if the rate of construction is maintained, this date may be advanced. All 30 beamlines, most using the high brilliance radiation that comes from insertion devices, will be in place by 1998. The SERC approved the U.K.'s contribution to the construction costs for 1992 (about £6 million, representing around 12 percent of the total).

The U.K. contribution to the 1992 budget of the ILL, approximately £10 million, was also approved. The U.K. will negotiate a new agreement on ILL to reduce its contribution after 1993 to release funds for other science. The ESF's annual report was reviewed by SERC, and the 1992 budget contribution of £276,000 was approved.

There will be a new center to coordinate data from four satellite-borne instruments in the Soho/Cluster Mission, a program to investigate the sun and its impact on Earth's environment. The £1.85-million center will offer a cost-effective focus for collaborative studies by providing validated data from the satellite in a standard format. Space plasma physicists in the U.K. will be able to access multi-instrument, multi-spacecraft data of unique quality.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE  August 1992	3. REPORT TYPE AND DATES COVERED  Multidisciplinary Research Bulletin		
4. TITLE AND SUBTITLE  European Science Notes Information Bulletin		5. FUNDING NUMBERS		
6. AUTHOR(S)				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Office of Naval Research European Office PSC 802 Box 39 FPO AE 09499-0700		8. PERFORMING ORGANIZATION REPORT NUMBER  92-04		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words)  European Science Notes Information Bulletin describes research being conducted and ideas being developed in Europe and the Middle East as reported by scientists assigned to the Office of Naval Research European Office and guest authors. It is published 6-8 times per year, on an irregular basis.				
14. SUBJECT TERMS  Chemistry                      Computer Science                      Materials Microbiology                      Oceanography                      Psychology			15. NUMBER OF PAGES  81	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT  UL	

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